COMBUSTION

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

February 1956

Photograph by Arthur M. Underwood

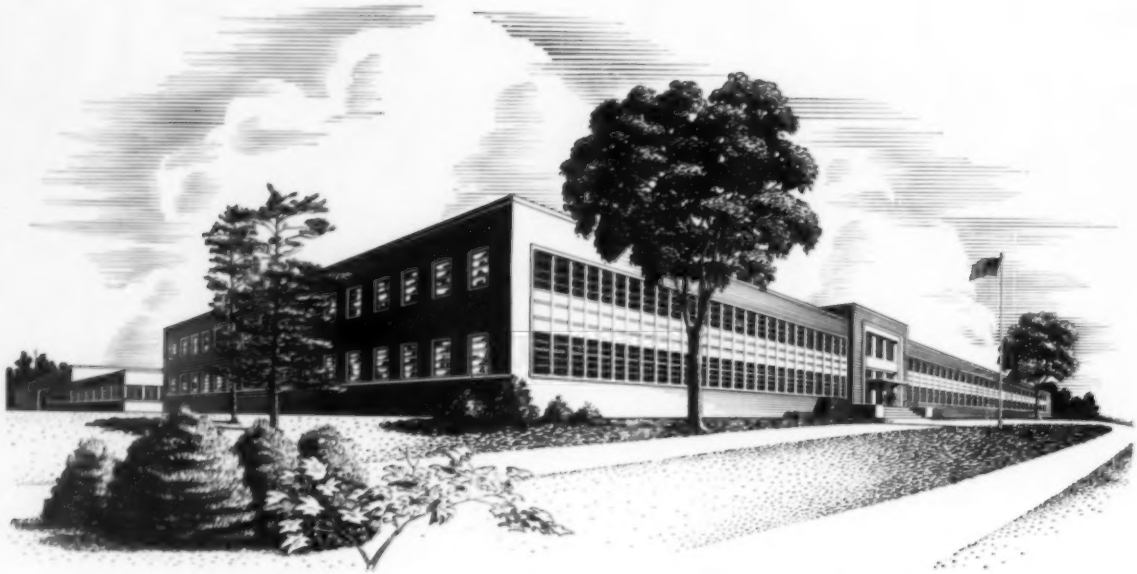
America's most attractively landscaped power plant—Russell Station of Rochester Gas & Electric Corp. See page 59

Evaluation of Furnace Heat Transfer Factors

Fuel Elements for Nuclear Reactors

Turbine-Driven vs Motor-Driven Feed Pumps

X-Ray Analysis in Chemical Cleaning



COMBUSTION ENGINEERING now building

NUCLEAR ENGINEERING AND DEVELOPMENT CENTER

On a 530-acre site in Windsor, Connecticut, Combustion Engineering is now building a Nuclear Engineering and Development Center. In addition to the Engineering and Administration Building, shown above, there will be a critical experiment facility for studying the physics and nuclear characteristics of reactor cores, a "hot" laboratory and a fuel element fabrication plant, together with related metallurgical, chemical and physical testing laboratories.

This multi-million dollar project, for which Stone & Webster Engineering Corporation are the architects and engineers, is scheduled for initial operation late this year and completion in early '57. In conjunction with new nuclear facilities recently placed in operation at the Company's Chattanooga, Tenn., plant, the Windsor plant will enable Combustion

to design, develop and manufacture
complete nuclear power reactor systems

Heavy components such as reactor vessels, boilers, plugs and shields will be manufactured at Chattanooga. Reactor cores, including fuel elements and control rods, will be produced at Windsor.

The new nuclear building at Chattanooga includes such equipment as a 13,000,000-volt betatron for fast X-raying of thick plate and welds; large precision machine tools capable of handling work up to 20 feet in diameter with accuracies comparable to those required in watchmaking; and cranes to handle loads in excess of 300 tons. A new dock is equipped to handle reactor vessels too large and heavy for rail or highway shipment. By virtue of these facilities, Combustion becomes the *first company in the world* to possess equipment especially designed for the manufacture of heavy reactor components and to be able to ship them by water to virtually all river and coastal ports.

The panel at the right reveals the Company's current activity in the nuclear field. With the new facilities now available or in process, and others recently authorized, Combustion is prepared to achieve the same position of leadership in nuclear power that it has long occupied in the field of conventional power generation.

C-E NUCLEAR WORK 1955-56

Contract to design, develop and build complete nuclear reactor system for a submarine. *(This contract made Combustion the country's third major contractor to AEC on the naval reactor development program, and the first to undertake such a contract with its own facilities.)*

Contract to design and build major reactor components for U.S.S. Seawolf.

Contract to design and build major reactor components for large naval surface ship.

Contract to design and build major reactor components for Submarine Advanced Reactor and Submarine Fleet Reactor Systems.

Contract to design and build major reactor components for Shippingport plant to be operated by Duquesne Light Company. *(This will be country's first commercial size nuclear power plant.)*

Contract to design and build major reactor components for Atomic Power Development Associates. *(This fast breeder reactor, to be operated by Detroit Edison Company, is regarded as the most advanced type projected to date for a commercial size power installation.)*

Agreement with AEC for design and evaluation studies of both large and small reactors and of fuel elements and their fabrication.

COMBUSTION ENGINEERING

Combustion Engineering Building
200 Madison Avenue, New York 16, N. Y

C-E

8-575

STEAM GENERATING UNITS; NUCLEAR REACTORS; PAPER MILL EQUIPMENT; PULVERIZERS; FLASH DRYING SYSTEMS; PRESSURE VESSELS; DOMESTIC WATER HEATERS; SOIL PIPE

COMBUSTION

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

Vol. 27 **No. 8**

February 1956

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The magazine is now reproduced and distributed to libraries on microfilm by University Microfilms of Ann Arbor, Michigan.

GERALD S. CARRICK
Business Manager

JOSEPH C. McCABE
Editor

GLENN R. FRYLING
Associate Editor

CARL G. UDELL
Circulation Manager

Published monthly by COMBUSTION PUBLISHING COMPANY, INC., 200 Madison Ave., New York 16
A SUBSIDIARY OF COMBUSTION ENGINEERING, INC.
Joseph V. Santry, Pres.; Charles McDonough, Vice-Pres.; Otto Strauss, Treas.; Irving B. Swigart, Secy.
COMBUSTION is sent gratis to engineers in the U. S. A. in charge of steam plants from 500 rated boiler horsepower up and to consulting engineers in this field. To others the subscription rate, including postage, is $4 in the United States, $5.50 in Canada; and $8 in Latin America and other countries. Single copies: Domestic, 40 cents: Foreign, 60 cents plus postage. Copyright 1956 by Combustion Publishing Company, Inc. Publication Office, Easton, Pa. Issued the middle of the month of publication.
Acceptance under Section 34.64, P.L. & R., authorized by United States Post Office.

BPA

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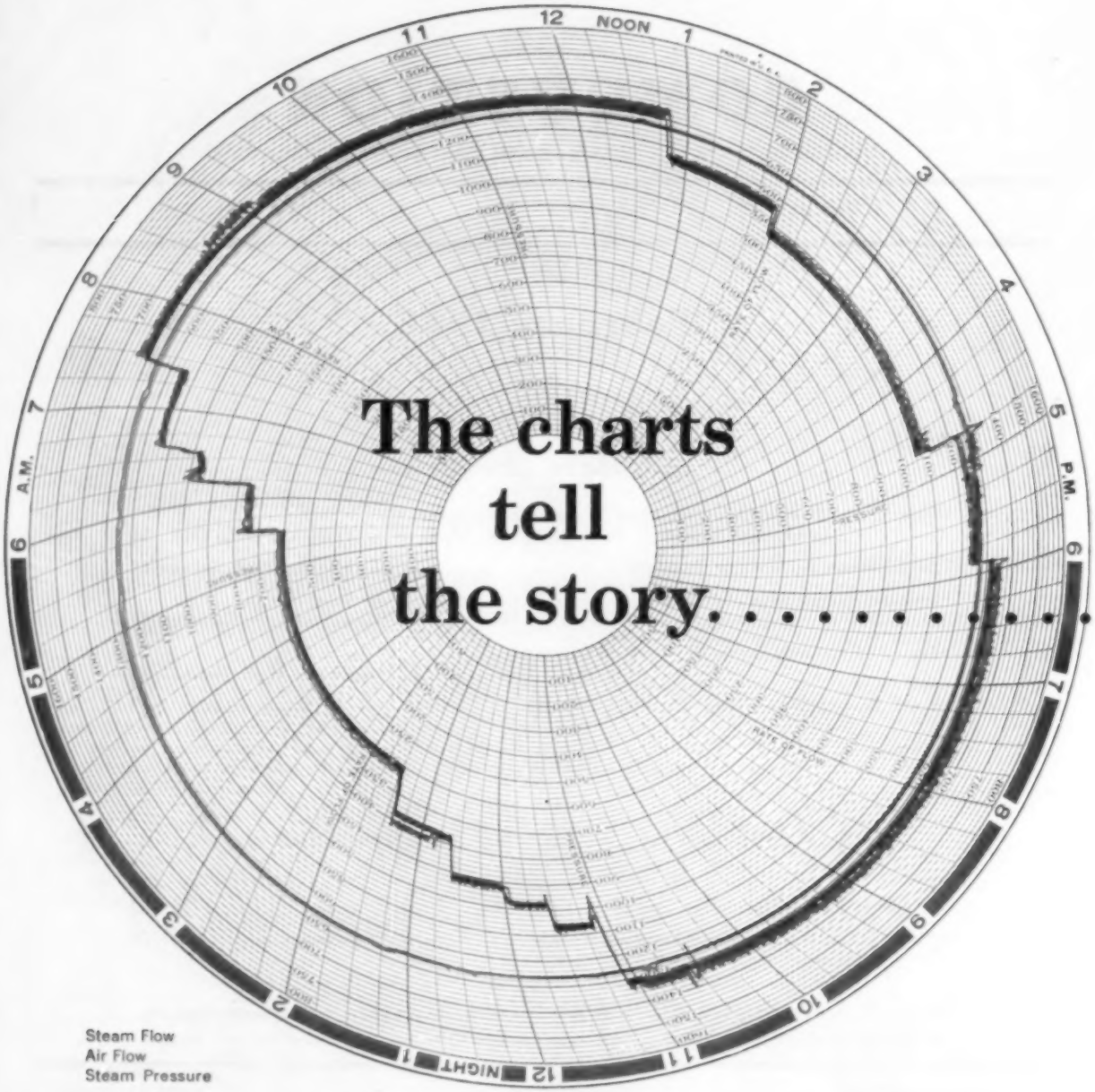


The charts tell the story. . . . . .

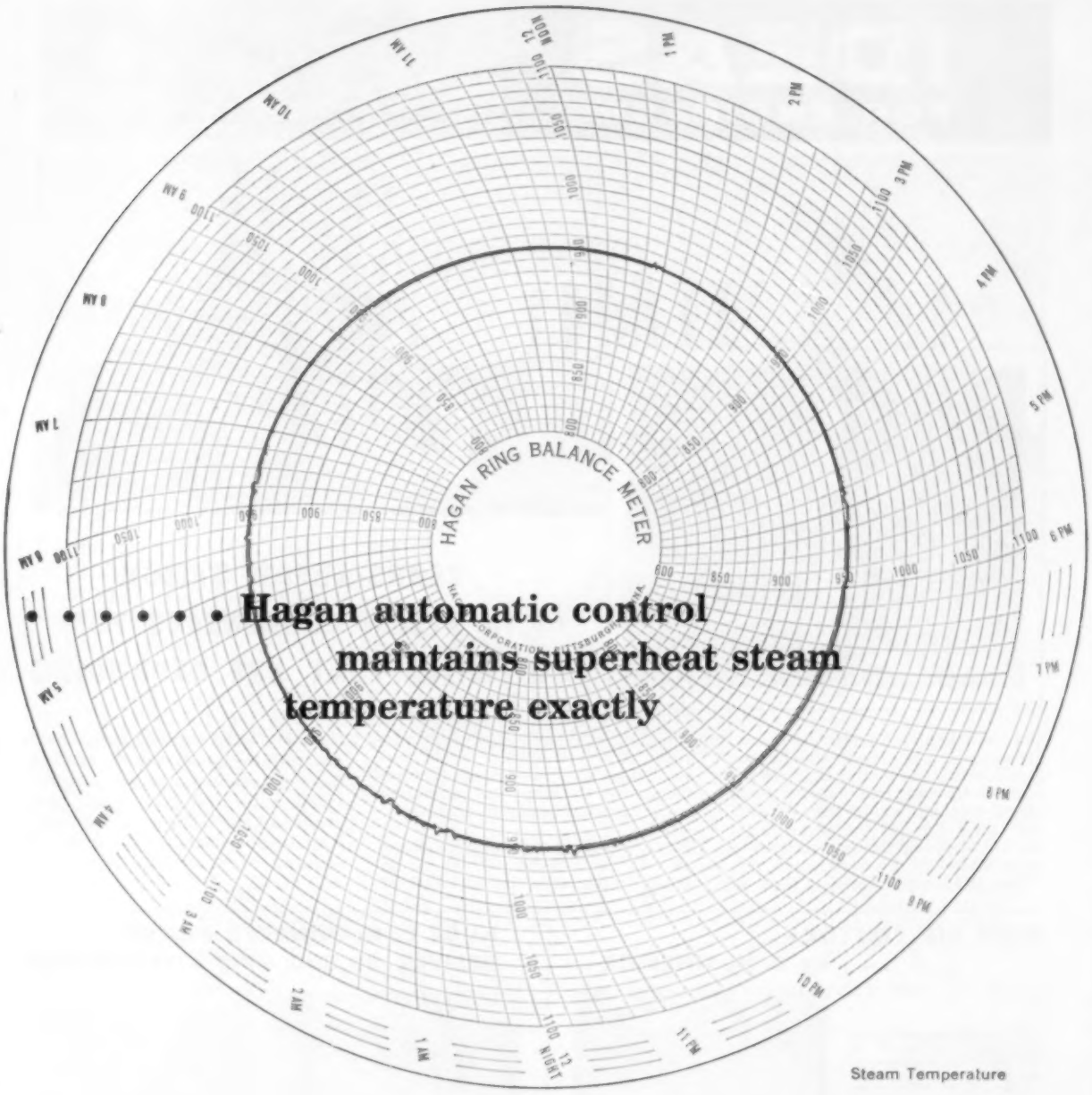
Steam Flow
Air Flow
Steam Pressure

HAGAN has the BEST automatic

If you don't believe it—look at the charts. The reasons for this superior performance lie in the use of Hagan's unique new PowrAmp temperature measuring system, and the sensitivity, speed and accuracy of its related control components.

The charts are typical of those produced daily on a new boiler at a large Florida utility. This exact control is achieved by positioning of the burner and with minimum use of spray.

If you feel that your steam temperature control can be improved—See Hagan.



Hagan automatic control maintains superheat steam temperature exactly

superheat steam temperature control

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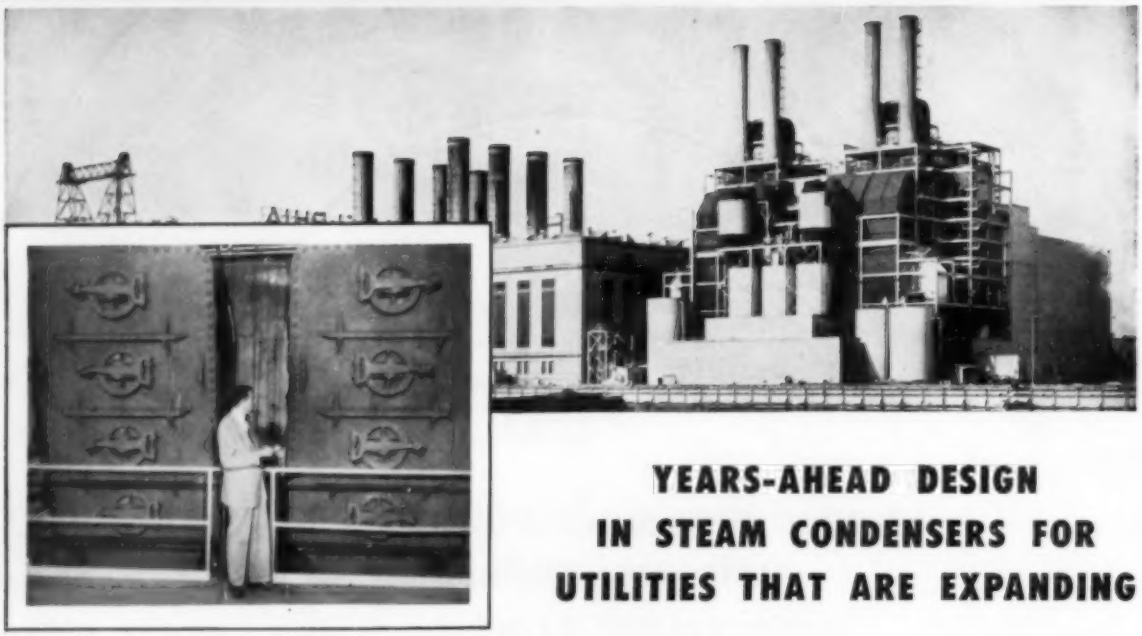
IDEAS FOR ENGINEERS

FROM C.H. Wheeler OF PHILADELPHIA



YEARS-AHEAD DESIGN IN STEAM CONDENSERS FOR UTILITIES THAT ARE EXPANDING

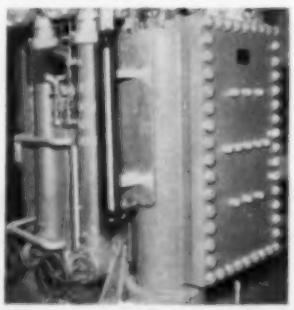
The Philadelphia Electric Company, for example, is one of the fastest growing utilities in the U. S. Here, men are thinking and working years ahead to take care of the "exploding" growth of the industrial Delaware Valley, and the ever-increasing population of Philadelphia, the "City of Homes". Nothing short of the most advanced design and efficiency of new equipment can be considered by the Philadelphia Electric Company to keep its generating capacity safely ahead of loading.

As part of their expansion program, two C. H. Wheeler 60,000 sq. ft. steam condensers are installed at the new Delaware Station. These are surface condensers of modern design; dual bank, single pass, divided water box type. Each unit condenses steam for a 125,000-kilowatt turbo-generator. Photo shows close-up of water box and manhole detail.

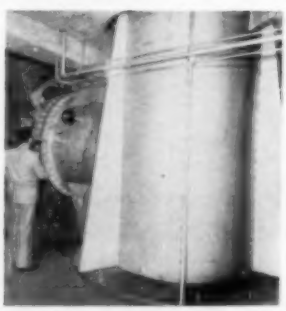
MAIN AIR EJECTORS . . . by C. H. WHEELER

An important factor in the performance of the C. H. Wheeler Steam Condensers is the efficiency of the main air ejectors. C. H. Wheeler has always been the source for the latest developments in steam jet air ejectors.

The streamlined, steel-shell Tubejet Ejectors installed at the Delaware Station are effecting considerable savings in space and providing dependable removal of air.



HUGE C. H. WHEELER PUMPS DELIVER 86,500 GPM RIVER WATER



Other modern C. H. Wheeler installations at the new Delaware Station are the circulator pumps. C. H. Wheeler has closely integrated circulator pump design with modern steam generating demands. Pictured here is one of two vertical mixed flow circulating water pumps feeding Delaware River water to the new C. H. Wheeler Steam Condenser. Capacity of each pump is 86,500 GPM.

Bulletins mailed on request.

Inquiries receive prompt attention.

Representatives in principal cities.

C.H. Wheeler OF PHILADELPHIA

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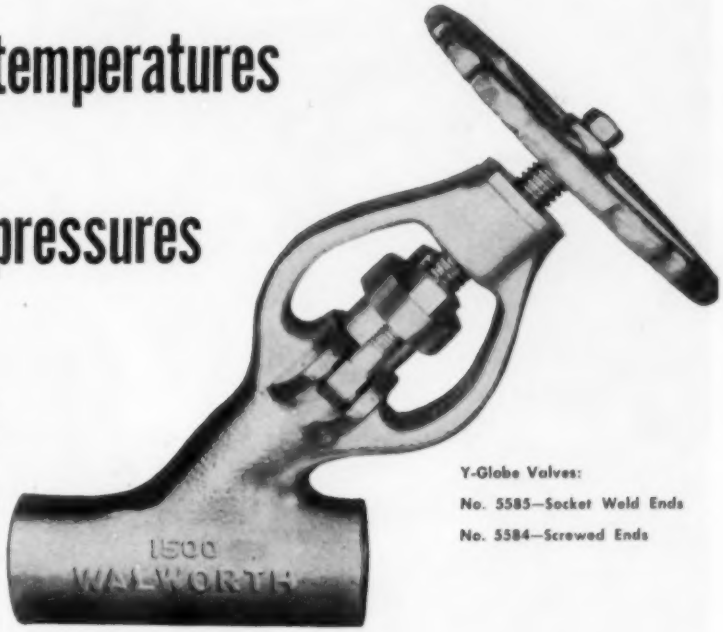
Walworth's NEW small cast steel valves

SERIES 1500 – SIZES ¼ to 2 inches

handle HIGH temperatures
HIGH pressures



Y-Globe Valves:
No. 5585—Socket Weld Ends
No. 5584—Screwed Ends

Walworth is proud to make these new Small Cast Steel Valves available to power stations . . . oil refineries . . . ships . . . wherever piping is subject to severe pressures and temperatures. Non-shock service ratings of these valves: 1500 psi–950F for steam; 3600 psi–100F for water, oil or gas. Cast of chromium molybdenum steel, they are compact and light, yet exceptionally strong. Both Y-Globe and Angle type valves are available.

Angle Valves:
No. 5587—
Socket Weld End
No. 5586—
Screwed End

Simplified Walworth design eliminates many of the valve problems encountered in high pressure service. Among the features of this new valve are:

INTEGRAL BODY AND YOKE – made from a single casting without threading or welding. Bonnet joint — always a potential source of leakage — is eliminated. Valves can be reassembled quickly and easily.

ROTATING DISC – prevents valve seat distortion and consequent leakage. Cuts down replacements.

WELDED SEAT RING – compensates for changes in pressure and temperature—eliminates a major source of leakage.

SPECIAL BACK SEAT BUSHING – permits repacking the valve under pressure with greater safety.

PACKING CHAMBER – designed to dissipate heat thus keeping packing rings at lower temperatures—gives them longer life.

These valves are available with either socket weld ends or screwed ends, in sizes ranging from ¼ to 2 inches. For further information on Walworth series 1500 Small Cast Steel Valves, see your local Walworth distributor, or write for Circular No. 134.

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. . . with new broader application
. . . with new attractive appearance

THE NEW HIGH-QUALITY Copes-Vulcan valves offer simplified designs and can handle any application at unlimited pressures for pipe sizes up to 16-inch. They have all the rugged dependability typical of Copes-Vulcan products. As always, they will be custom-designed with ports exactly suited to individual operating conditions.

NEW VERSATILITY IN DIAPHRAGM-TYPE, CV-D

You can now assure yourself of unsurpassed Copes-Vulcan quality in valves for operation at unlimited pressures. You may have either direct or reverse action. Rangeability is high.

Optional features include: Cooling fins and lubricator for stuffing box that will maintain low friction over a longer packing life . . . a top or side-mounted hand wheel to permit emergency operation . . . Auto-lock to hold the valve in its last position, should control air fail.

NEW SIMPLICITY IN PISTON-TYPE, CV-P

This is the high-duty Copes-Vulcan valve—simplified in appearance and design, but retaining the superb operating characteristics that have made former Copes valves so outstanding.

It is the new Type CV-P, for application where you need the ultimate in valve-operating force . . . more than is available from a diaphragm . . . where you need extremely precise positioning . . . where you want the finest valve that money can buy.

You can get this new Type CV-P Valve for pipe sizes up to 16-inch, for unlimited pressures.

Rangeability is high. Response can be characterized to meet your operating requirements.

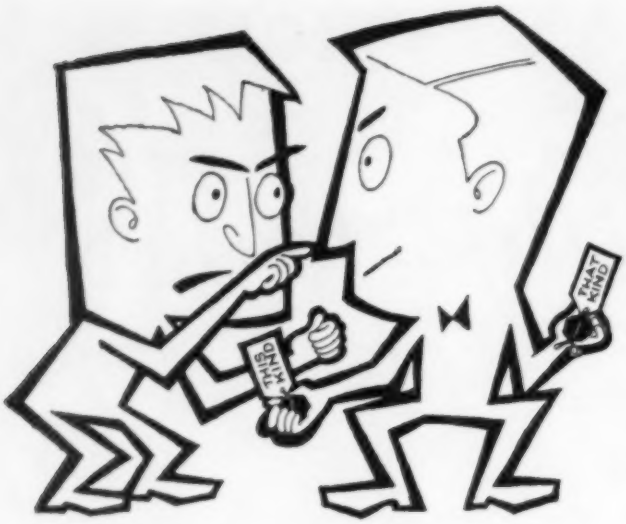
Write, or get in touch with your Copes-Vulcan man for complete information.

COPES-VULCAN DIVISION

BLAW-KNOX COMPANY

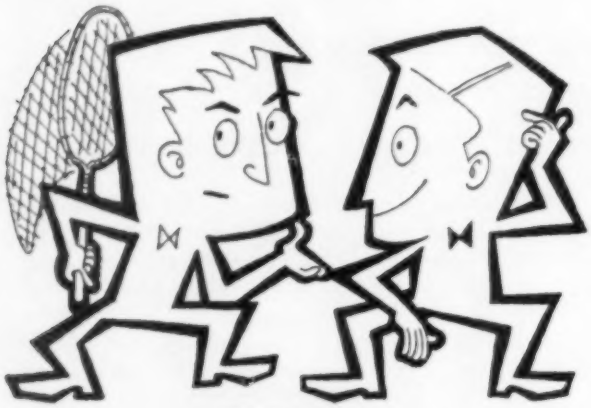
Erie 4, Pennsylvania

REDUCING VALVES



What's the big idea buying several kinds of coal for our steam plants?

It's a good idea. The kind of coal that burns most economically in the old boilers isn't efficient for the new ones.



How do you know you're right?

Look at the coal bills. We are generating more steam at a lower fuel cost. You can tell from the ashes we are getting more complete combustion, and there's less clinkering.

Where did you get this idea, anyway?

From the C & O Coal Department. They convinced us that different types of burning equipment need different types of coal. From the high quality coal produced on the C & O, we selected the quality and size of coal that works best in our particular installations.

P.S.

There's a lot more to buying coal than the cost per million BTU. Why not contact coal producers on the C & O to solve your particular fuel requirements, or write to: R. C. Riedinger, General Coal Traffic Manager, Chesapeake & Ohio Railway Co., Terminal Tower, Cleveland 1, Ohio, for the assistance of a C & O fuel service engineer.

Chesapeake and Ohio Railway

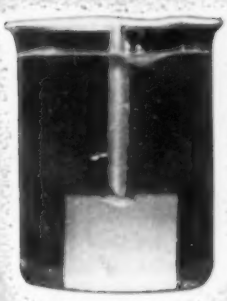
WORLD'S LARGEST CARRIER OF BITUMINOUS COAL

A New, Better Coagulant

NALCO 600

POLYELECTROLYTE

Alum



Alum plus
typical polyelectrolyte

Alum plus
Nalco 600

● As a coagulant in water clarification, and under many process coagulation conditions, new and different Nalco 600 has shown such great promise, both in performance and economy characteristics, that it has now been made available for general use as an established member of the Nalco family of chemical aids to industry.

Extremely difficult coagulation conditions provide especially economical applications for Nalco 600. It can be used alone or in conjunction with other coagulants. A very low dosage of Nalco 600 usually permits as much as 50% reduction in dosage of alum, activated silica, iron sulfate or clay type treatments . . . and results in a cleaner, clearer supernatant liquid.

Nalco 600 was invented in the Nalco Laboratories, and is being manufactured *only* by Nalco. For complete data on Nalco 600, and expert technical assistance to solve your clarification and coagulation problems, call Nalco now.

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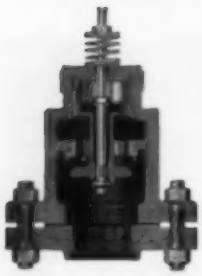
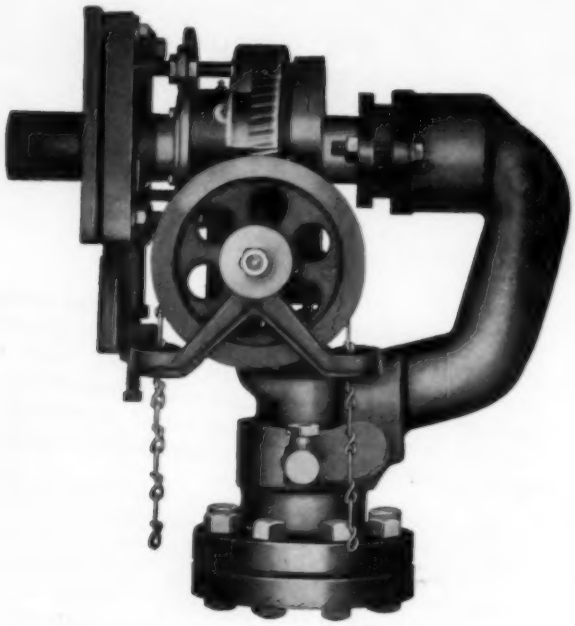


Bayer Balanced Valves are famous for their long life and continued tightness



Bayer Single Chain Balanced Valve Soot Cleaner

WITH THE Bayer Balanced Valve Soot Cleaner the balancing chamber above the piston disc impounds steam when the valve closes, thus relieving valve parts from shock. The valves remain *steam tight* because the dashpot action causes the valve to seat gently. Unbalanced valves close with a hammer stroke and soon become leaky.

When stationary elements are used the Bayer stationary balanced valve head may be furnished. Thus all the cleaning elements of the entire soot cleaner system can be controlled by the Bayer quick-opening Balanced valves. This gives a uniform or standard valve controlled system and in addition, when high pressures require a reduction in pressure *at each individual element* this Balanced valve unit, whether used with a stationary or a revolving element, can be fitted with an integral orifice plate valve.

Piping connections can be kept in the same plane and undesirable bends or fittings avoided when the Bayer Balanced Valve is installed with both stationary and revolving elements.

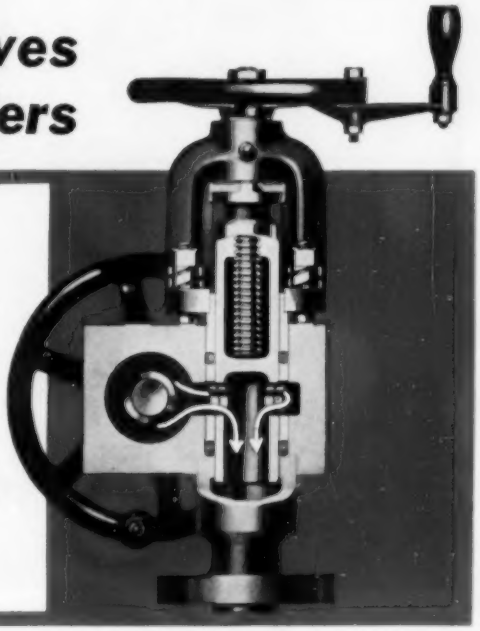
Valve parts are standard and interchangeable and when high pressure heads are fitted with orifice plate regulating valves these parts are also interchangeable.

THE BAYER COMPANY

SAINT LOUIS, MISSOURI, U. S. A.

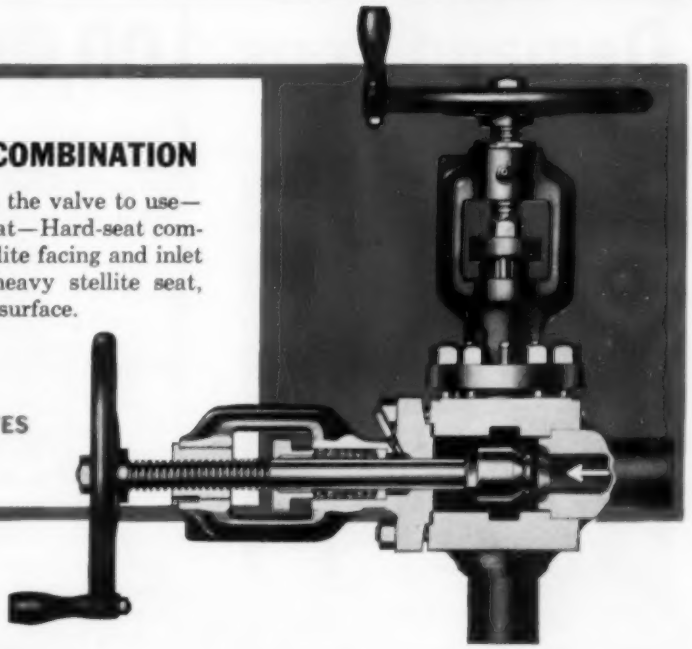
UNIT TANDEM

rugged blow-off valves for high pressure boilers



HARD-SEAT—SEATLESS COMBINATION

■ For boilers up to 1500 psi, this Yarway Unit Tandem Blow-Off Valve offers the maximum in dependable service. A one-piece forged steel block serves as the common body for the Yarway Stellite Hard-seat blowing valve and the Yarway Seatless sealing valve. All interconnecting flanges, bolts and gaskets are eliminated. The Unit Tandem at right is sectioned through Seatless Valve to show balanced sliding plunger in open position and free flow.



HARD-SEAT—HARD-SEAT COMBINATION

■ For boilers to 2500 psi, this is the valve to use—Yarway's Unit Tandem Hard-seat—Hard-seat combination. Disc has welded-in stellite facing and inlet nozzle has integral welded-in heavy stellite seat, providing smooth, hard-wearing surface.

OVER 4 OUT OF 5
HIGH PRESSURE PLANTS
USE YARWAY BLOW-OFF VALVES

Write for Yarway Catalog B-434

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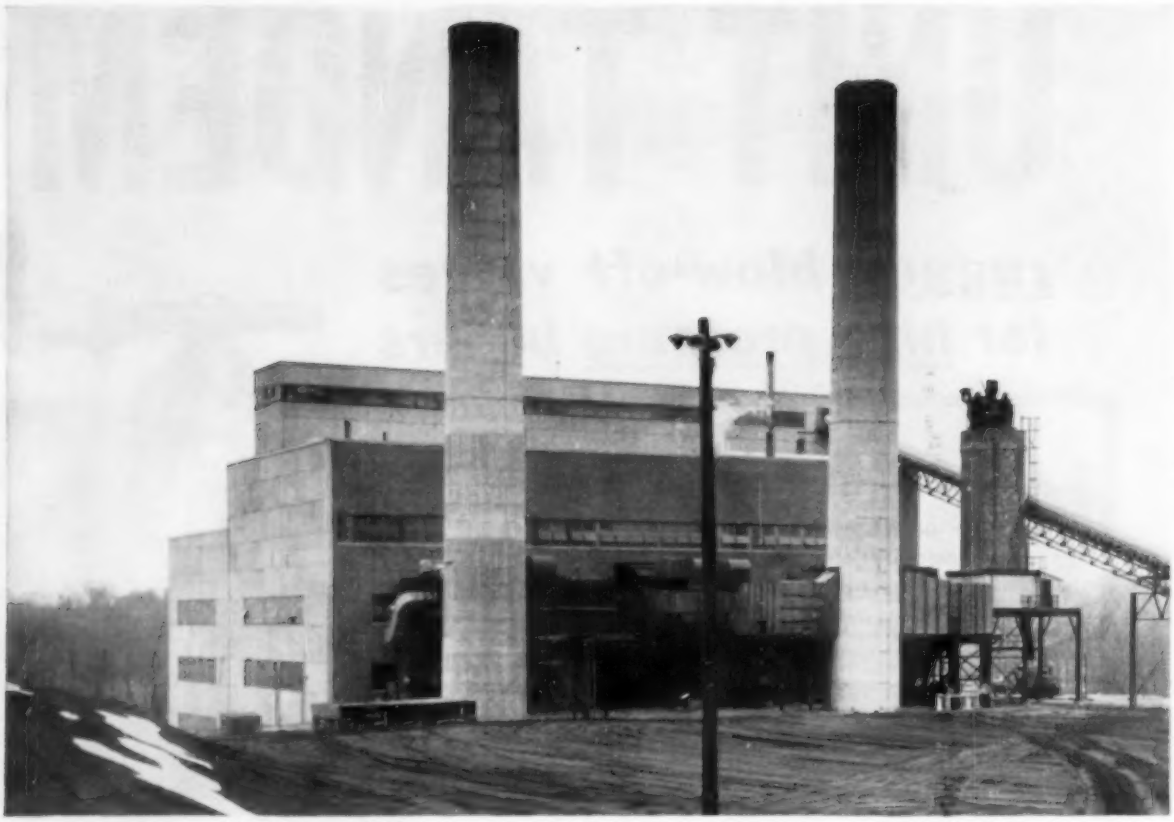
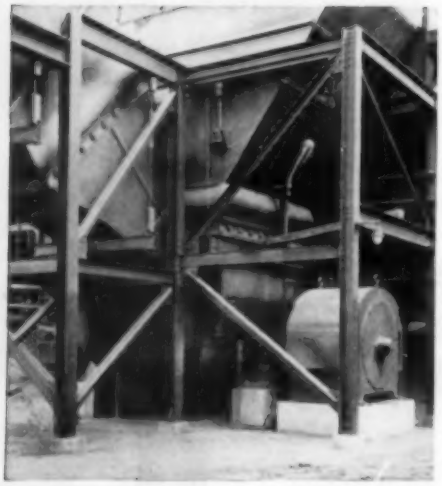
YARWAY **BLOW-OFF VALVES**



Sabrooke Station's third generating unit adds 30,000 kw: raises system capacity of Central Illinois

Demand tops 100,000 kw mark



American Blower Sirocco Induced Draft Fan at Sabrooke Station is rated at 184,000 cfm @ 340° F @ 14.5" sp @ 600 hp. American Blower Draft Fans are also installed at company's Fordam Station.

Central Illinois Electric and Gas Co. puts new generating unit on the line to meet area needs; relies on American Blower Mechanical Draft Fans.

Shortly after the third steam-generating unit began operation in October 1955 at Sabrooke Station, the Central Illinois Electric and Gas Co. marked a milestone. *For the first time in the company's history*, the electrical needs of its Rockford service area exceeded 100,000 kw!

Indeed an important event, the new unit demonstrates this growing company's ability to more than meet the demands of the future . . . a future in which American Blower equipment has an important role.

Like the Central Illinois Electric and Gas Co., many other progressive, investor-owned utilities have also decided on American Blower equipment. They know from past-performance records that American Blower products are reliable, and are built to meet rigid power-plant requirements.

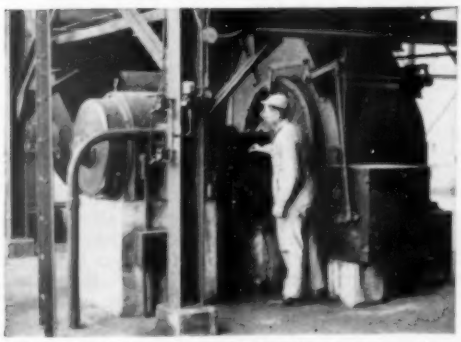
We'd be pleased to give *you* full facts on our Mechanical Draft Equipment, Fly Ash Precipitators, Heavy Duty Steam Coils, and Gyrol Fluid Drives for boiler feed-pump and fan control. Just give our nearby branch office a call.

American Blower

reports on progress in power

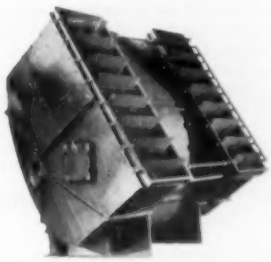
Electric and Gas Co. to 156,450 kw.

in Rockford, Ill.

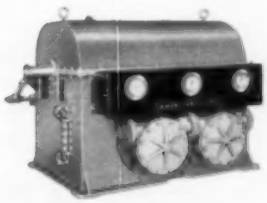


American Blower Forced Draft Fan has capacity of 104,000 cfm @ 90°F @ 9.5" sp @ 250 hp.

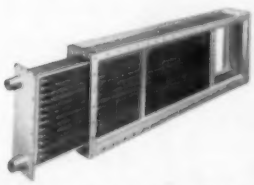
AMERICAN BLOWER PRODUCTS SERVE AMERICA'S POWER NEEDS



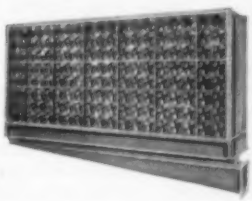
Mechanical Draft Fans for forced and induced draft.



Gyrol Fluid Drives for boiler feed-pump and fan control.



Heavy duty steam coils for high-pressure duty.



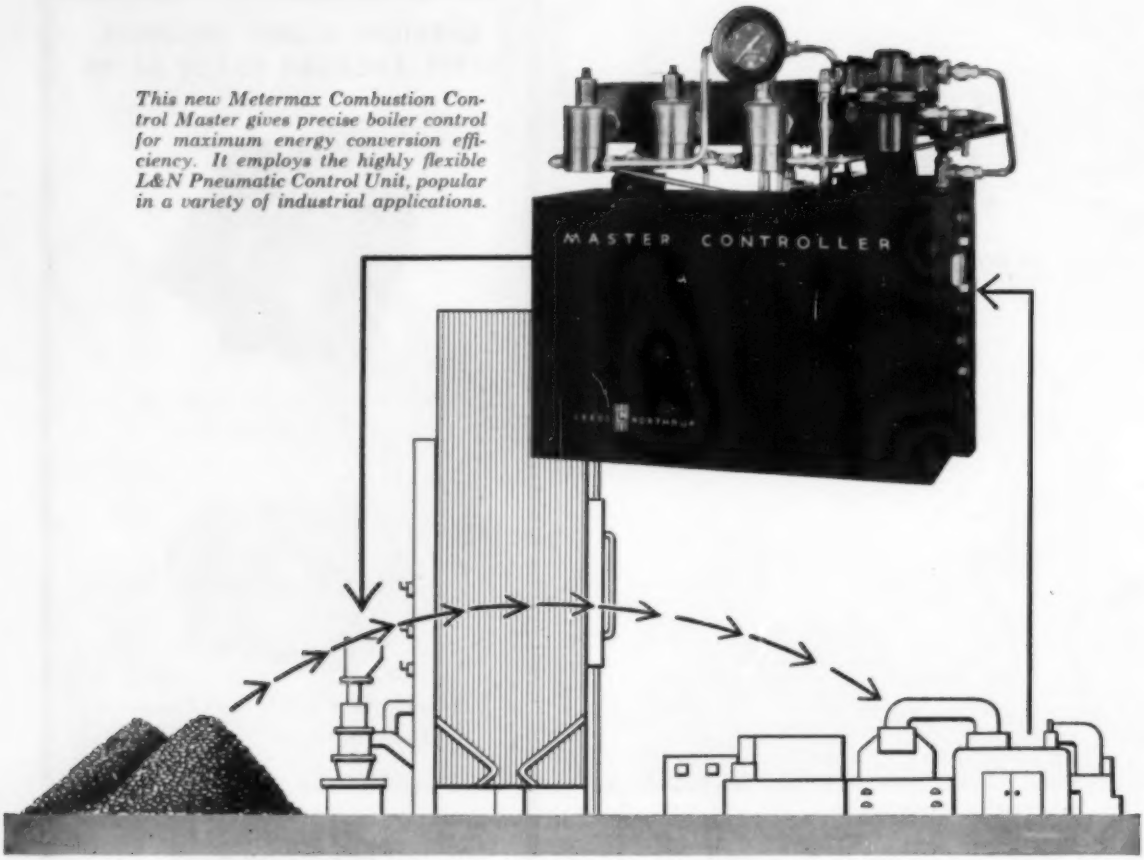
Collectors and precipitators for dust and fly ash control.

AMERICAN BLOWER CORPORATION, DETROIT 32, MICH. • CANADIAN SIROCCO COMPANY, LTD., WINDSOR, ONTARIO

Division of American-Standard

AMERICAN 75th ANNIVERSARY YEAR BLOWER

This new Metermax Combustion Control Master gives precise boiler control for maximum energy conversion efficiency. It employs the highly flexible L&N Pneumatic Control Unit, popular in a variety of industrial applications.



Let this "cost-conscious" brain

HELP SOLVE YOUR COMBUSTION CONTROL PROBLEMS

■ The widely-used Metermax Combustion Control now features this new Master Controller which gives you precise, stable boiler control over a wide load range. Because of its unitized design this Master coordinates the three fundamental control actions. Thus, you're assured of a precise blending of: *proportional action* to meet boiler load changes, *reset action* to maintain a constant steam pressure at all loads, and *rate action* to gear response to the speed and intensity of load swings.

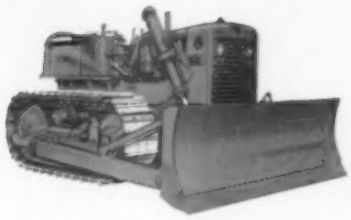
You get wide-range stability because the Master automatically "modulates" its own response as boiler load decreases to reduce control action at low loads for maximum stability. Your proportional, reset, and rate settings, once made to meet a given boiler load condition, are correct for all loads . . . automatically. You need not change or compromise your initial settings. These settings are easy to make, with an independent, calibrated dial for each action.

Boiler operators find this Master easy to work with. First, they can transfer to automatic quickly, because they can balance it to existing boiler conditions simply by turning a single, panel-mounted knob. The transfer is "bumpless," there's no boiler upset . . . no operator attention is needed after transfer. Second, operators get instant action from the Master because there are no long control tubing runs. Control circuits are electric all the way from the control room to the "control center" where the Master and the individual Metermax Controllers are located. This, plus electric transmission to the electric drive units, provides instant response. And third, the Master adjusts itself as load decreases, for low-load stability, thus relieving the operators of this additional duty.

Precise control . . . wide-range stability . . . fast response . . . ease of operation. That sums up what you can expect of Metermax Combustion Control.

For more information on this Metermax Master, write to Leeds & Northrup Company, 4972 Stenton Ave., Philadelphia 44, Pa.

LEEDS NORTHRUP
instruments automatic controls • furnaces



ALLIS-CHALMERS COAL HANDLING EQUIPMENT

SOLD but not forgotten

by your Allis-Chalmers dealer

When you invest in Allis-Chalmers equipment, you are getting far more than just a modern machine. Your dealer offers you the opportunity to do a better job at lower cost. He wants your equipment to give A-1 performance day in and day out. His reputation depends on it.

That's why your Allis-Chalmers dealer puts so much importance on good preventive maintenance practices . . . encourages you to take full advantage of his modern servicing facilities.

You're always sure of

TRUE ORIGINAL PARTS

from your Allis-Chalmers dealer

Parts made in the same factory, to the same rigid specifications as original equipment, are your assurance of getting top performance and long life. Treated, packaged and sealed against rust and dust, True Original Parts are stocked in quantity by each dealer to give you quick service close to your job.

And you can have confidence in his

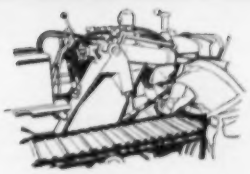
FACTORY-TRAINED MECHANICS, FACTORY-APPROVED METHODS

IN THE SHOP

Specialized facilities include factory-approved tools and all necessary equipment for complete service. Factory-approved methods are used to save you time and money, assure finest workmanship.

ON THE JOB

Factory-trained servicemen are ready to help you, day or night. Their technical know-how and practical experience get the job finished fast . . . at lowest possible cost to you.

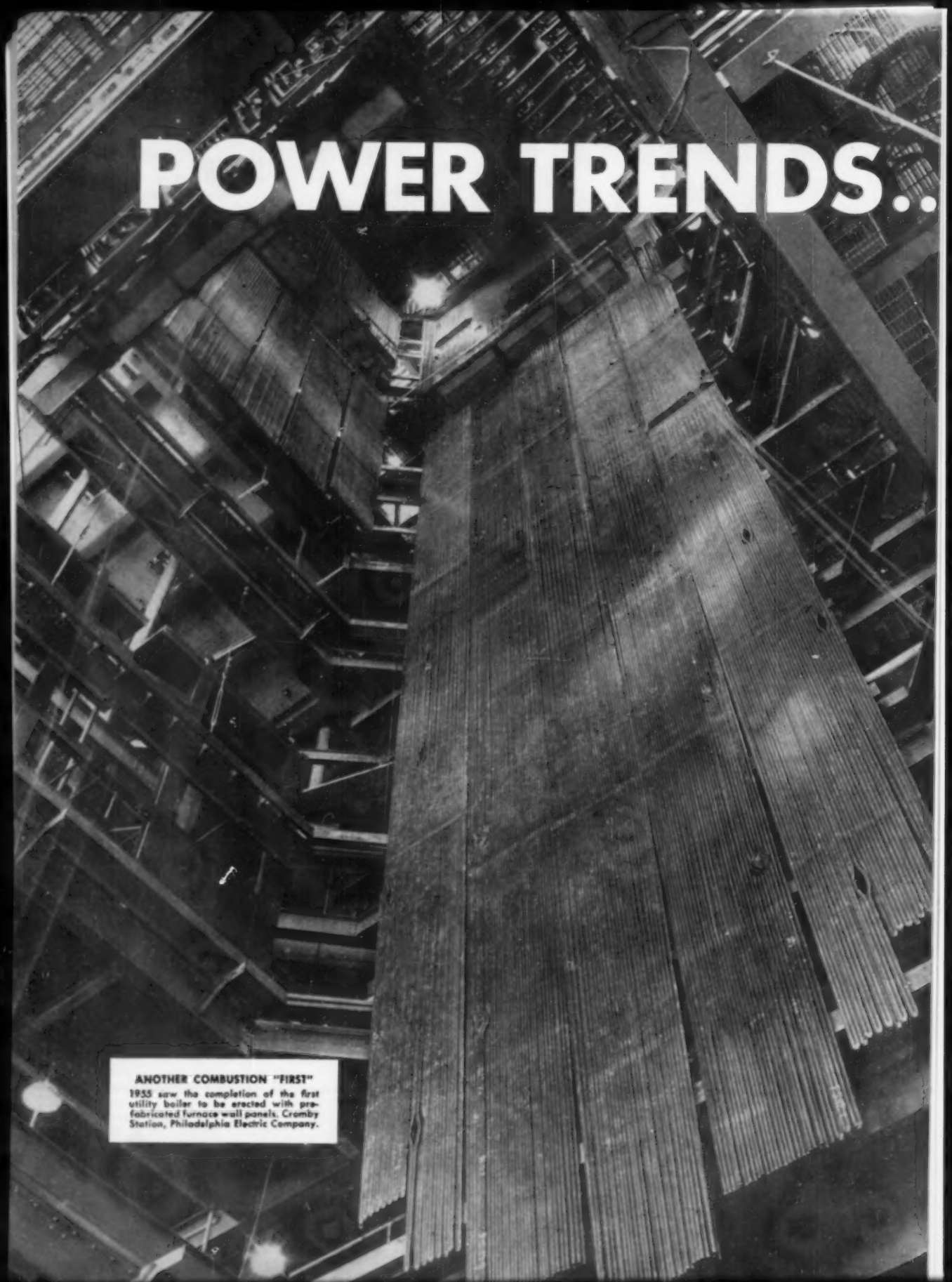


You can depend on your Allis-Chalmers dealer

ALLIS-CHALMERS, CONSTRUCTION MACHINERY DIVISION, MILWAUKEE 1, WISCONSIN

ALLIS-CHALMERS

POWER TRENDS..



ANOTHER COMBUSTION "FIRST"

1955 saw the completion of the first utility boiler to be erected with prefabricated furnace wall panels. Cromby Station, Philadelphia Electric Company.

••• as revealed by 1955 orders for **C-E UTILITY BOILERS**

Orders placed for C-E Utility Boilers in 1955 were of such volume and diversity as to provide a comprehensive picture of present-day practices and trends in the power field. The total capacity represented by these orders was more than

7,000,000 kilowatts

Reheat boilers accounted for over 90 per cent of this capacity. Since the use of reheat has become almost universal practice with respect to medium size and larger units, the following comments on trends are based on orders for *reheat boilers only*.

UNIT CAPACITIES— Bigger turbine-generators continue to be the order of the day. Average capacity is about 148,000 kw. Eight units are rated at 200,000 kw or higher, the two largest being 325,000 kw.

STEAM PRESSURES— Most notable trend is growing adoption of 2400-lb range. Twelve units, representing 31% of the capacity, are in this category. 1955 orders also included one supercritical pressure unit — 3500 psi. Units from 2000 psi up represent nearly 60% of the capacity.

STEAM TEMPERATURES— Almost 45% of the units will have primary steam temperature of 1050 F and one unit will be designed for 1100 F. These units account for 55% of the capacity.

CONTROLLED CIRCULATION— Continuing its dominant position in the high pressure field, C-E Controlled Circulation designs accounted for 73% of all C-E reheat capacity ordered last year and 100% of the capacity for pressures from 2000 psi up.

FIRING— 87% of the capacity will be fired by C-E Tilting Tangential Burners. Coal stays well out in front as the No. 1 utility fuel, being specified as the primary or exclusive fuel for nearly 75% of the units. However, virtually all these units, whether the primary fuel be coal, oil or gas, will be designed for easy convertibility to the use of other fuels.

DUAL FURNACES— Completely separated furnaces will be used for 20% of the units, including all units from 200,000 kw up. (Nine C-E dual furnace units are now in service and six more, ordered prior to 1955, are in process.)

COMBUSTION ENGINEERING

Combustion Engineering Building, 200 Madison Avenue, New York 16, N. Y.

STEAM GENERATING UNITS; NUCLEAR REACTORS; PAPER MILL EQUIPMENT; PULVERIZERS; FLASH DRYING SYSTEMS; PRESSURE VESSELS; HOME HEATING AND COOLING UNITS; DOMESTIC WATER HEATERS; SOIL PIPE

B-900

70 Years ago we used ads like this to tell buyers about Bell & Zoller Coal. We've done a lot of growing—and made a lot of changes since then. • But one thing hasn't changed—the famous free-burning, low ash, high heat-producing quality of Bell & Zoller products. • The proudest statement we can make on our 70th Anniversary is the same one we could make in 1886: Superb Quality Coal, We Mine It—ZEIGLER, MOSS HILL, ORIOLE, MURDOCK, LIBERTY SMOKELESS, BUCKHORN, SPARTA... and you can get it today through your nearest Bell & Zoller office.

Bell & Zoller Coal Company

70 YEARS OF SERVICE TO COAL USERS

BELL BUILDING, CHICAGO 1, ILLINOIS

Cleveland • New York • St. Louis • Minneapolis
Omaha • Milwaukee • Louisville • Washington, D.C.
Terre Haute, Ind. • Mount Hope, W.Va.

"Wet Coal Flows Much Better Over Stainless-Clad Steel..."

These three stainless-clad steel coal chutes at Potomac Edison's Smith Station have provided trouble-free service for 2, 2½ and 3½ years respectively.

The R. Paul Smith Station of the Potomac Edison Co., at Williamsport, Md., had experienced considerable hangup trouble due to wet coal. Now they find that "wet coal flows much better over stainless-clad steel than it did over carbon steel. This is a great factor in our using it." Stainless-clad equipment installed to date includes three coal chutes and one 36' coal pipe. These four units have averaged 3 years of service with practically no stoppage of coal flow. Clad steel's satisfactory performance has resulted in Smith Station's planning to replace carbon steel equipment as it wears out with stainless-clad steel.

Consistent economy is the major reason why clad is repeatedly chosen for replacement and original installation service. This economy results directly from clad steel's built-in qualities—a layer of stainless steel integrally and permanently bonded to strong, low-cost carbon steel backing plate. This combination provides lower initial cost than solid high-alloy plate, yet provides the same long-term, maintenance-free protection. Clad has repeatedly demonstrated its ability to provide as much as 10 years' service without any measurable loss of gage. With hard use clad steel develops smooth, mirror-like finish that means free coal flow.

For detailed information on stainless-clad steel's exceptional performance in coal handling service, write for Bulletin 740. Lukens Technical Service Department is available to work with your builders and engineers to put clad to work for you. In addition we will supply the names of qualified equipment builders who are experienced with your problems. Write to the Manager, Marketing Service, 684 Lukens Building, Lukens Steel Company, Coatesville, Pennsylvania.

LUKENS

STAINLESS-CLAD STEELS

FOR INTERIOR COAL HANDLING EQUIPMENT

LUKENS STEEL COMPANY, COATESVILLE, PENNSYLVANIA

PRODUCER OF THE WIDEST RANGE OF TYPES AND SIZES OF CLAD STEELS AVAILABLE ANYWHERE

Research-Cottrell

makes both

The choice of a straight precipitator or a combination mechanical-electrical precipitator for fly ash recovery depends on many factors—size and composition of the fly ash, efficiency desired, space available for the equipment, initial cost, etc.

Whatever your fly ash problem you can be sure of unbiased recommendations from Research-Cottrell, because we offer both types—and have done so for many years.

The cutaway drawings on the next page show several design features of both the straight Cottrell precipitator and the combination mechanical-electrical precipitator offered by Research-Cottrell.

These basic designs, as well as Research-Cottrell's custom engineering of each installation, are backed by over 40 years experience and over 500 fly ash collectors. For more details on this equipment write for Bulletins GB and FA.

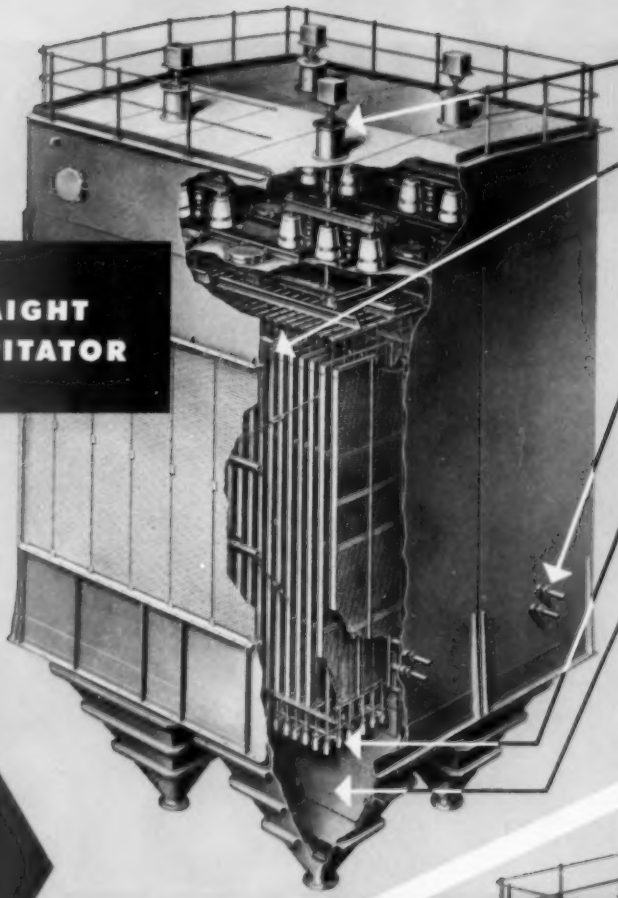
Precipitator is designed and constructed for many years of heavy-duty, all-weather service.

RESEARCH-COTTRELL, INC.

A Wholly Owned Subsidiary of Research Corporation

Main Office and Plant: Bound Brook, N. J. • 405 Lexington Ave., New York 17, N. Y. • Grant Building, Pittsburgh 19, Pa. • 228 N. La Salle St., Chicago 1, Ill. • 111 Sutter Bldg., San Francisco 4, Cal.

STRAIGHT PRECIPITATOR



1 Continuous, automatic discharge electrode rapping insures optimum performance.

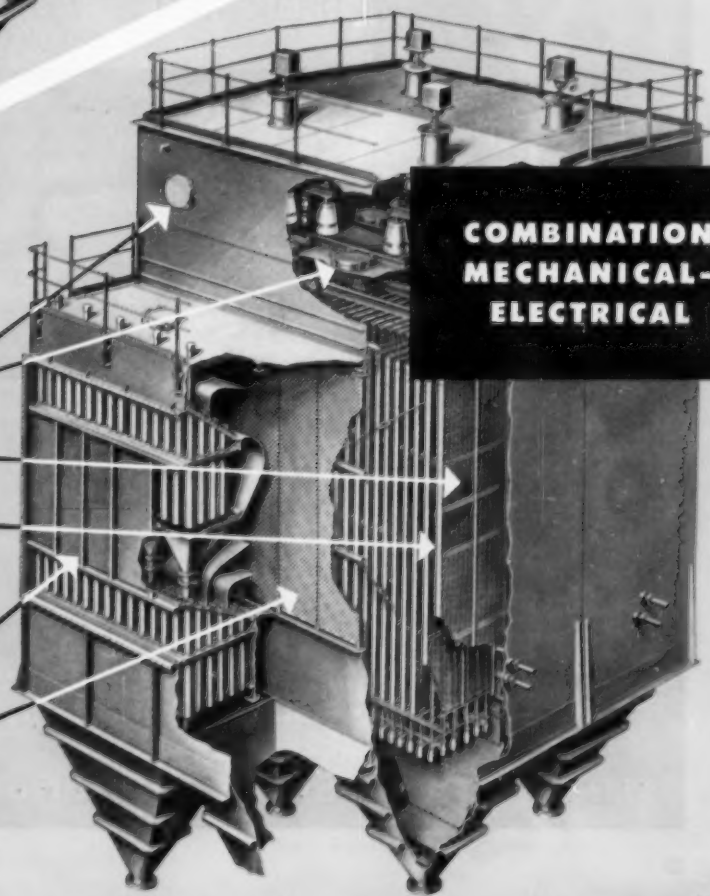
2 Hook-type collecting electrode hangers, quickly installed, insure uniform distribution of rapper vibration throughout entire collecting surface.

3 Rapping puffs prevented by automatic and continuous cleaning of collecting electrodes with Magnetic Impulse Rapper (patents pending).

4 Plumb-bob discharge electrodes are individually weighted and positioned by a steadying frame for maximum efficiency.

5 Hopper baffle prevents gas sneakage around electrodes.

COMBINATION MECHANICAL-ELECTRICAL



6 Easy access to high tension equipment.

7 No moving parts in gas stream—minimizes maintenance.

8 End and intermediate baffles provide quiescent zones and prevent re-entrainment of collected dust.

9 Compact double-deck mechanical collector (patented) provides large capacity in a small area.

10 Double-deck mechanical collector design insures even gas distribution at precipitator inlet.

Ljungstrom® field engineers assure you of maximum return on your preheater investment

Your Air Preheater Corporation field engineer aims to visit your installation at least once a year. It's his job to give you the help and advice you need to assure you of maximum return on your Ljungstrom Air Preheater investment.

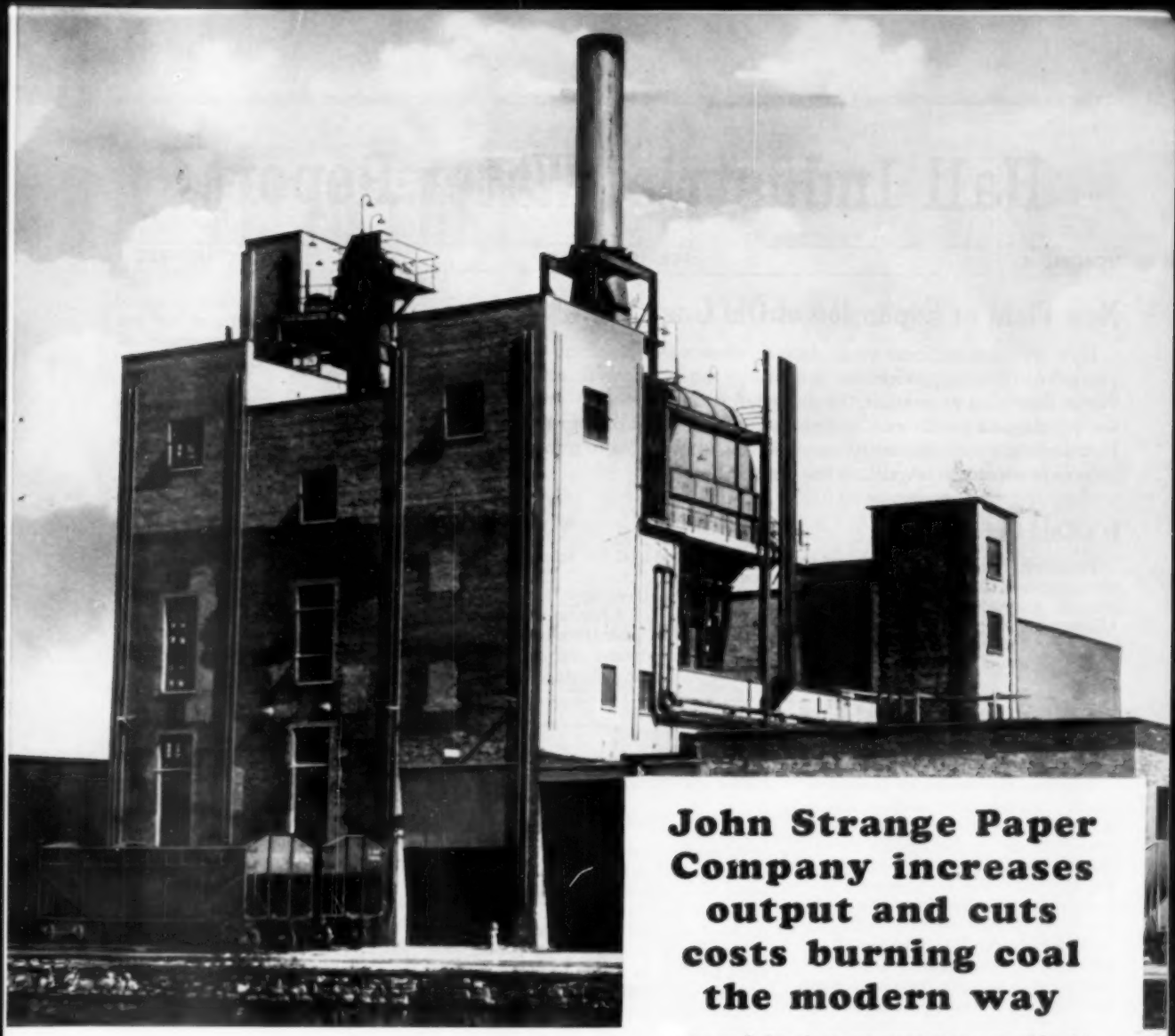
This field service is another factor in making the Ljungstrom the most economical heating surface on the modern boiler. And it helps explain why 7 out of 10 modern preheater installations are Ljungstroms.

Get all the details on the Ljungstrom Air Preheater. Why it cuts fuel costs . . . helps maintain higher boiler efficiencies . . . why it speeds cleaning and maintenance. You'll find all the details in the new, 38-page reference manual, "Ljungstrom Air Preheaters." Write for your free copy, today!

Advantages of the Ljungstrom Air Preheater

- Size for size, recovers more heat than any other type.
- Reduces fuel consumption. Permits use of lower-grade fuels. Increases boiler output and reliability.
- Eliminates cold spots . . . keeps corrosion to a minimum.
- Easier, faster to clean and maintain.
- Requires far less supporting steel and is quickly erected.

The Air Preheater Corporation 60 East 42nd Street, New York 17, N. Y.



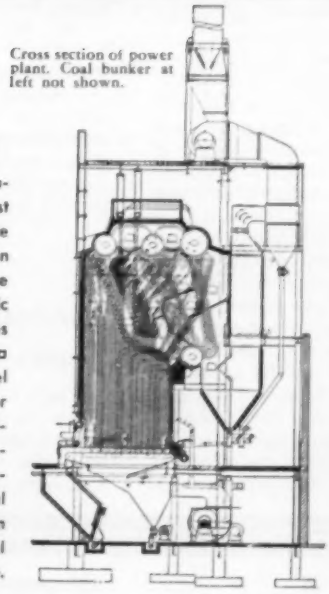
John Strange Paper Company increases output and cuts costs burning coal the modern way

Steam and electric power represents a considerable percentage of overall costs in paper mill production. In addition to this cost problem, the power plant of the John Strange Paper Co., Menasha, Wis., lacked sufficient capacity to meet the mill's demand for steam and power.

In an effort to trim costs and increase capacity, the company called in the consulting firm of Cummins & Barnard, Inc., Ann Arbor, Mich., to recommend a modernization program. Based on those recommendations, today John Strange burns coal in highly efficient steam-generating equipment. The remodeled installation includes completely modern coal-handling and pneumatic ash-handling equipment as well as two automatic control systems. Costs have been curtailed; steam and power supply is dependable. Most important, the mill machinery operates at higher speed, resulting in a 10% increase in production.

For further information or additional case histories showing how other plants have saved money burning coal, write to the address below.

NATIONAL COAL ASSOCIATION
Southern Building, Washington 5, D. C.



Cross section of power plant. Coal bunker at left not shown.

facts you should know about coal

In most industrial areas, bituminous coal is the lowest-cost fuel available • Up-to-date coal burning equipment can give you 10% to 40% more steam per dollar • Automatic coal and ash handling systems can cut your labor cost to a minimum • Coal is the safest fuel to store and use • No smoke or dust problems when coal is burned with modern equipment • Between America's vast coal reserves and mechanized coal production methods, you can count on coal being plentiful and its price remaining stable.

Hall Industrial Water Report

VOLUME 4 FEBRUARY 1956 NUMBER 1

New Plant or Expansion of Old One

How well you engineer your plant services may determine whether you get continuous production or operation like a paralytic centipede. Water for steam generation, for cooling, for use in process—and water leaving the new plant—*can* be designed to be the least of your troubles. But the best time to listen to someone who knows how to make water behave is while you are still in the planning stage.

It's Cold Out There!

Frequent subzero weather with temperatures as low as −45 at the site of a proposed new plant in Minnesota was an important factor in the choice of a heating system by a large mining company planning to process iron from taconite. Space heating constituted about ninety percent of the load. Buildings to be heated were widely scattered over a large area.

When a high-pressure hot-water heating system was decided upon, water treatment had to be considered from two angles: protection of the boilers and protection of the heating system. Hall Laboratories was invited to study the raw water available and to recommend treatment.

Water could be obtained from either of two intakes from the surface supply; samples from both were analyzed. The types of metal used in construction of the heating system were determined, zeolite softening and deaeration of makeup, chemical conditioning and proportional chemical feeding facilities were thoroughly discussed in a survey report by Jack Summerville, Hall staff engineer. After completion of the survey report, it was learned that well water might have to be used temporarily because of delay in completion of the surface supply pipe line. Because the well water does not have as desirable a composition as the surface water, Hall urged that the pipe line be completed as quickly as possible and recommended that the well water be zeolite softened even though regenerations would be much more frequent.

The boilers have now been boiled out and, on Hall's recommendation, acid cleaned to insure thorough cleanliness of the heater surfaces. The plant is beginning operation.

Faith Justified By Performance

When an Eastern paper specialty manufacturer decided to build a new plant in California, the chief engineer wrote: "In dealing with the problem of water supply, water treatment, and so forth, we felt it desirable to call in Hall Laboratories, not only because of the past relations which have existed for so many years, but because we intend to retain Hall Laboratories as consultants for our California plant."

To start the survey, Hutcheson Page, of Hall's New York office, conferred with the plant management about the purchase of their boiler. After extensive checking of specific requirements, a factory-assembled, water-tube boiler was ordered.

Hall Laboratories already had experience with the water in the chosen locality in California. This provided a sound basis for recommending the proper pretreating equipment.

Because of the potential cost of water supplied from a city aqueduct, the plant wished to use water from its own wells. Hall recommended pretreatment equipment flexible enough so that it could properly prepare any of the various waters available for future use in any standard type of boiler operating at 250 psi. A salt regenerated cation-anion exchange system was suggested and accepted.

The plant also has followed other recommendations made by Hall for internal boiler-water treatment as well as treatment of steam by Hagamin.® A recent service report from Hall field engineer Orville Morrow states that the plant is maintaining very good treatment control.

South of the Border

Hall Laboratories pursues the "Good Neighbor" policy by helping many clients in South America and the West Indies on a consulting as well as on a continuing service basis.

A client in Maracaibo planned to install an additional boiler plant adjacent to the one already serviced by Hall Laboratories. Hall helped the plant select evaporator feedwater pretreating equipment, chemical feed pumps, pH meters, and helped plan the laboratory layout prior to start-up. Then Jack Summerville of the Hall headquarters staff made a trip to Maracaibo to help start operations, with special attention to their hot lime-gypsum reactor, pressure filters, hot zeolite softener, evaporators, and the treatment of their feedwater-condensate and boiler-water systems.

Continuing satisfactory conditions have been maintained by correspondence between the plant and Pittsburgh headquarters, supplemented by an annual consulting trip by Hall staff engineer, Alex Henricks.

Industrial Water Problems Require Special Handling

There are no "stock answers" to industrial water problems. For information write, wire or call Hall Laboratories, Inc., Hagan Building, Pittsburgh 30, Pa.

Water is your industry's most important raw material. Use it wisely.

FLUID COKE: *Development in Petroleum*

Refining Produces Valuable New Fuel

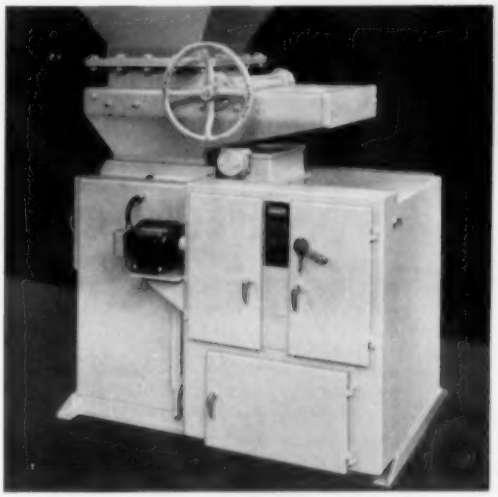
A relative newcomer to the power field, fluid coke seems destined to attain prominence in a short time. Although used in the charge of a by-product coking oven, and for various metallurgical processes, etc., fluid coke will find its principal use as a combustion material.

What is fluid coke? Fluid coke is a product of a new refining process developed and patented by the Esso Research and Engineering Company, a process which produces a high yield of gas-oil, which can be cracked to high octane gas, and a relatively low yield of coke. The coke itself differs greatly from regular petroleum coke. Particles are small, like fine sand. The particles pour freely, and are clean in comparison with other coke. Fluid coke burns with a minimum of ash. Even allowing for an extra high ratio of unburned carbon, up to 20%, heat output is comparable to that of coal of about 14,000 B.t.u./lb. Auxiliary fuel such as oil or high volatile coal must be used to bring coke up to ignition temperature and maintain a regular flame.

How much fluid coke is being produced? Present capacity of refineries is only 350 tons per day. However, total capacity of all plants now in the building or planning stage will run about 2,500 tons per day, or about ¼ of the production of petroleum coke in this country. All companies are producing the coke under license from Esso.

Who is using fluid coke? First boiler installation designed to use fluid coke as a primary fuel will be the Delaware Power & Light Company plant at Delaware City, Delaware. Coke will come from the refinery built by Tide Water Associated Oil Company. Another eastern utility has provided an outlet for the production of Esso's Baltimore refinery. Other utilities and industrial power installations will follow suit as production of the coke increases.

A small free sample of the fluid coke is available — simply write to the address listed below.



Plants which will use fluid coke as commercial fuel include the new Delaware City Power Station of Delaware Power & Light Company. This plant will serve the new Tide Water Associated Delaware Flying —A— Refinery now under construction 15 miles south of Wilmington with C. F. Braun & Co. as engineers and contractors. Stock Equipment Company is proud to announce that specially-designed S-E-Co. Valves and Scales, like the ones pictured above, will be used to weigh coke as it goes to the pulverizers.

SPECIALISTS IN
BUNKER TO PULVERIZER AND
BUNKER TO STOKER EQUIPMENT

STOCK Equipment Company

745-C HANNA BLDG., CLEVELAND 15, OHIO

Bailey Recorder for receiving pneumatic and electric signals.

Pick any four, plug in, and record

Here is a receiver recorder, custom-built *by you* to meet your needs, no matter how changeable, how complex. On a single chart you can record any four measured variables—and interchangeable receivers permit new combinations almost at will.

Individual plug-in pneumatic or electronic receivers—and corresponding integrators—are interchangeable in the four identical frame slots. You can select any combination; even including two receivers and their two integrators.

Think what this can mean to you! Parts inventories are minimized; re-use of components keeps instrumentation costs economically low when cycle changes are frequent—and you can even tie in with your existing transmitters.

Ask for Product Specification E12-5.

Measured Variables

- % combustibles
- combustion
- conductivity
- density
- differential
- draft
- flow
- liquid level
- % oxygen
- pH
- position
- pressure
- ratio
- smoke density
- specific gravity
- speed
- temperature
- vacuum

ONLY BAILEY OFFERS ALL THESE ADVANTAGES IN A SINGLE RECORDER

- Pre-calibrated plug-in receiver units
- Up to four pneumatic or electronic receivers —or two receivers and two integrators
- Any four variables on one chart—easily read and interpreted
- A full year's ink supply at one loading
- Faster ordering—from stock
- Minimum inventory of parts
- Minimum instrument investment for process cycle expansion or alteration

BAILEY METER COMPANY

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Controls for Power and Process

Controls for TEMPERATURE PRESSURE GAS ANALYSIS FLOW · LEVEL RATIO · DENSITY

"DESIGN OF PIPING SYSTEMS"

(Second Edition)

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- Derivation of Acoustic Vibration Formulas
- Charts and Tables

AS POWER PIPING BECOMES MORE CRITICAL

M. W. KELLOGG'S DESIGN EXPERIENCE KEEPS PACE

As temperatures and pressures increase in steam-electric power plants, the problems involved in designing, engineering, and fabricating main and reheat steam piping multiply themselves many times over. This emphasizes, more than ever, the value of the long experience, in the laboratory and on the job, of The M. W. Kellogg Company—leader in the power piping field.

More evidence of M. W. Kellogg's accumulated piping design experience and ability to tackle each new power piping project in its stride, is the company's new 400-page book, "Design of Piping Systems"—published early this year by John Wiley & Sons. The most comprehensive work ever made available publicly on the physical design of piping, it is one of the many ways M. W. Kellogg cooperates with consulting engineers, engineers of power generating companies, and manufacturers of boilers, turbines, and allied equipment. An outline of contents is shown above.

FABRICATED PRODUCTS DIVISION

THE M. W. KELLOGG COMPANY, 225 BROADWAY, NEW YORK 7, N. Y.

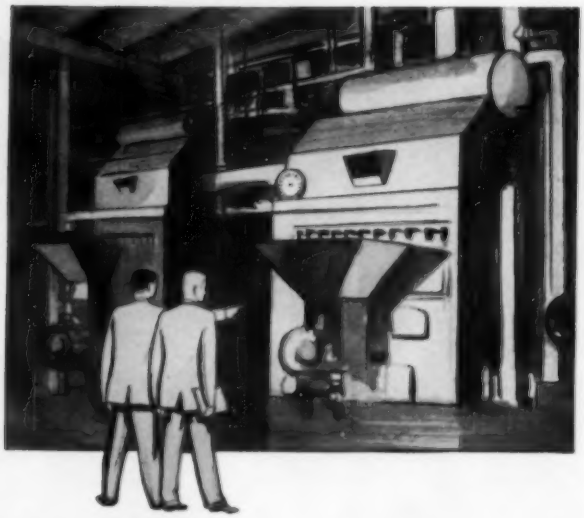
The Canadian Kellogg Company, Ltd., Toronto • *Kellogg International Corporation, London*

SUBSIDIARIES OF PULLMAN INCORPORATED

You can be sure of getting your copy of this limited edition of "Design of Piping Systems" by writing now to M. W. Kellogg, asking to be notified as soon as the book is available. Ask also for the new, free, 12-page booklet, "Piping Flexibility Analysis," which shows how M. W. Kellogg's various flexibility analyses techniques can cut piping design and construction costs.

POWER PIPING—THE VITAL LINK

competent coal counsel



whether for heat, power or special purpose

Competent coal counseling service is available to you, without obligation. The men who staff the N&W coal bureaus have had years of experience with the utilization of coal, and they are well qualified to discuss your problems with you. They will be glad to tell you all about high-quality Fuel Satisfaction* and how it can meet your specific requirements more efficiently and economically. Feel free to contact the bureau nearest you for dependable advice on the selection, transportation and utilization of the *right* coal for your purpose.

ROANOKE
N&W Coal Traffic Dept.
Telephone 4-1451,
Ext. 423, 313, 249
Roanoke 17, Virginia

BOSTON
833 Chamber of
Commerce Building
Telephone LIberty 2-2229
Boston 10, Massachusetts

CHICAGO
Room 604,
208 South LaSalle Street
Telephone RAndolph 6-4634
Chicago 4, Illinois

CINCINNATI
908 Dixie Terminal Building
Telephone DUnbar 1-1325
Cincinnati 2, Ohio

CLEVELAND
1819 Union Commerce Building
Telephone MAin 1-7960
Cleveland 14, Ohio

DETROIT
1907 Book Building
Telephone
WOodward 1-2340 or 1-2341
Detroit 26, Michigan

ST. LOUIS
Room 1201, 1218 Olive Street
Telephone MAin 1-1180
St. Louis 3, Missouri

WINSTON-SALEM
1105 Reynolds Building
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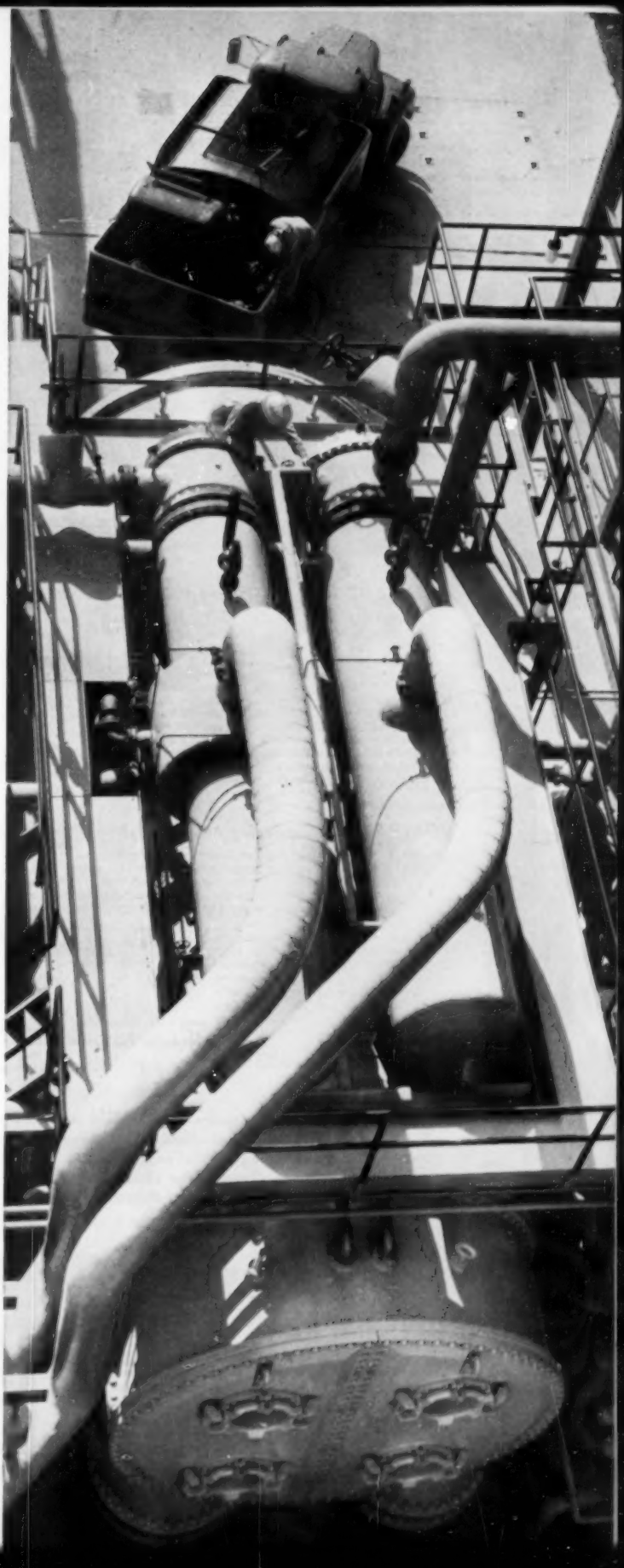

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Because the advantages of MULTICLONE are so clear-cut, so vitally important, so far-reaching in the savings they make, we urge you to make a factual unbiased comparison of MULTICLONE fly ash collection equipment against *any other* in the mechanical recovery field. Only by making such a comparison can you fully appreciate the major savings and greater performance you get by installing MULTICLONE Collectors!

COMPARE Recovery Efficiency!

It is a recognized fact that the separating efficiency of a cyclonic tube increases as the tube diameter decreases because smaller tubes generate greater centrifugal forces. The patented vane in the MULTICLONE makes the use of small tubes *practical* without complicated manifolding and permits compacting many small tubes into one simple, highly efficient unit. MULTICLONE's higher centrifugal forces throw out not only the large, medium and small particles, but also an unusually high percentage of the *extremely small* particles of 10 microns and less. Result—*more complete recovery of all suspended particles from the gas stream!*

COMPARE Space-Saving Compactness!

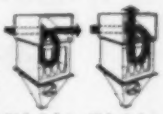
Plant space costs money—particularly at today's high construction costs. Because the MULTICLONE is more compact, size for size, it makes *really important* savings in space and plant costs. Note in the chart how the MULTICLONE requires substantially less space—*both in floor space and cubic space*—than any other unit of comparable capacity and performance. *This means vital savings in construction costs!*

Make	Relative Space Requirements In Sq. Ft.	In Cu. Ft.
Multiclone	1.0	1.0
Collector A	2.1	1.8
Collector B	5.9	3.2
Collector C	6.8	3.9

COMPARE Dollar-Saving Adaptability!

Savings in space is just one of many ways MULTICLONE reduces installation costs. Because the shape of the unit can be readily varied (long and narrow, short and wide, or square) to fit available spaces, the MULTICLONE can often be tucked into odd corners and waste areas too restricted for other equipment.

Moreover, inlet-outlet ducts can be varied—side-inlet side-outlet, or side-inlet top-outlet—to meet low headroom or restricted side clearance requirements . . . and the single-inlet single-outlet duct design permits greater flexibility and simpler installation. *These all add up to vital savings in installation costs!*



Side inlet, Side outlet *Side inlet, Top outlet*

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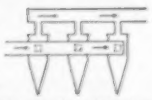
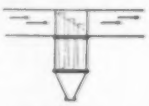
The MULTICLONE is simple and inexpensive to maintain because there are no highspeed moving parts to repair or replace . . . no pads or filters to clean or renew . . . nothing to choke the gas flow or increase draft losses as suspended materials are recovered. In addition, the square, flat-sided shape of the MULTICLONE and its straight inlet and outlet ducts are far simpler to install and insulate. And since the recovered material from an entire bank of tubes is collected in a *single* hopper, it is much easier to service and maintain than the multiple hoppers of conventional cyclone units. *Here again, the MULTICLONE saves in many ways—all of them important!*



Conventional Cyclone



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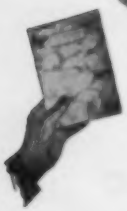

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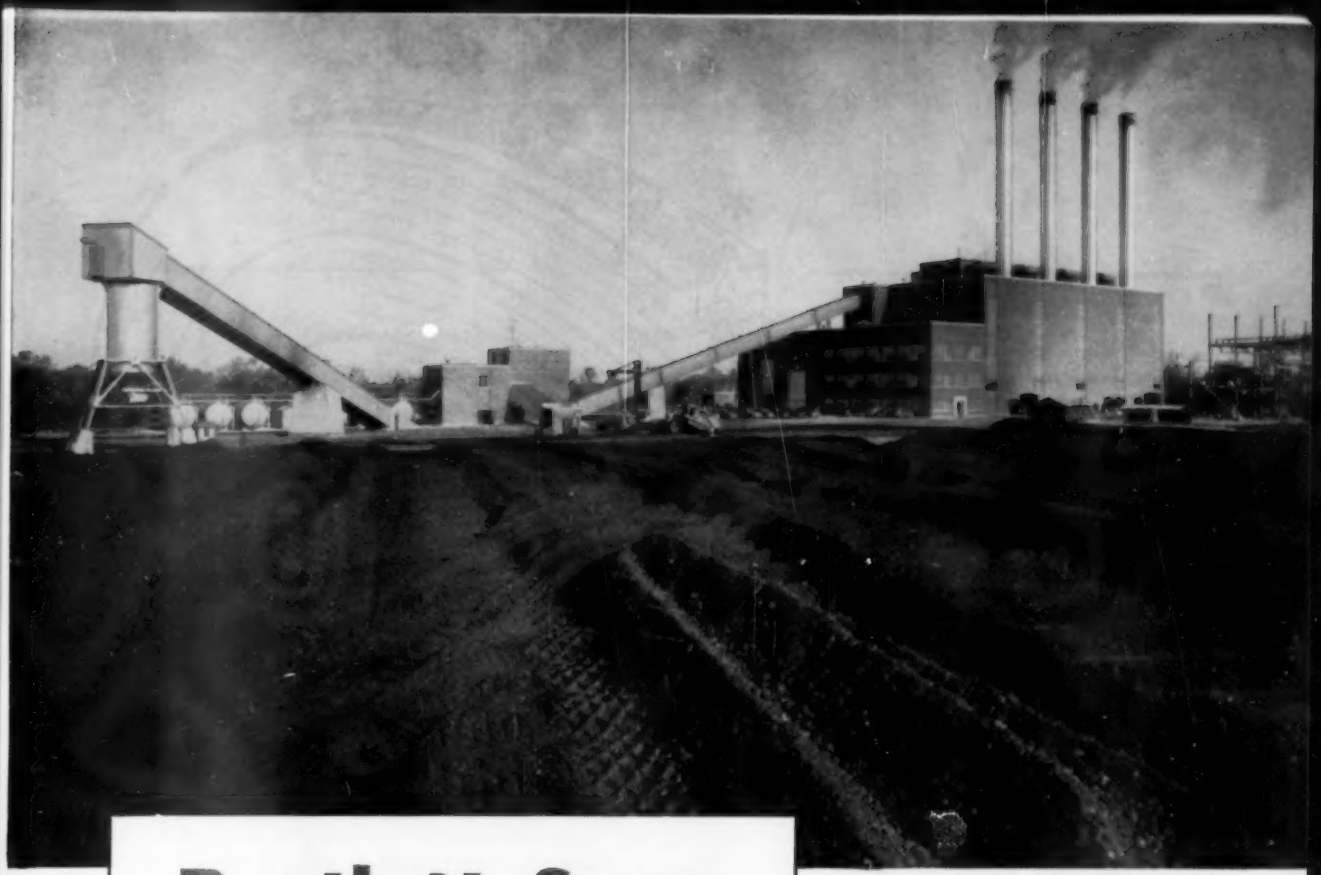

General View of Meredosia Power Station
Central Illinois Public Service Co.
Sargent and Lundy
Consulting Engineers

Bartlett-Snow coal handling at Meredosia

● The illustration above shows the first 100,000 KW unit of a plant which is to be extended into a 200,000 KW station. All coal handling equipment including the receiving and reclaiming hoppers and grillage, duplex feeder, conveyors, galleries, breaker screen and all supporting structures were fabricated in our shops, and installed by us, to Sargent and Lundy's specifications. For maximum efficiency and fixed unit responsibility, let the Bartlett-Snow coal handling engineers, with their long experience and complete facilities, work with you on your next job.

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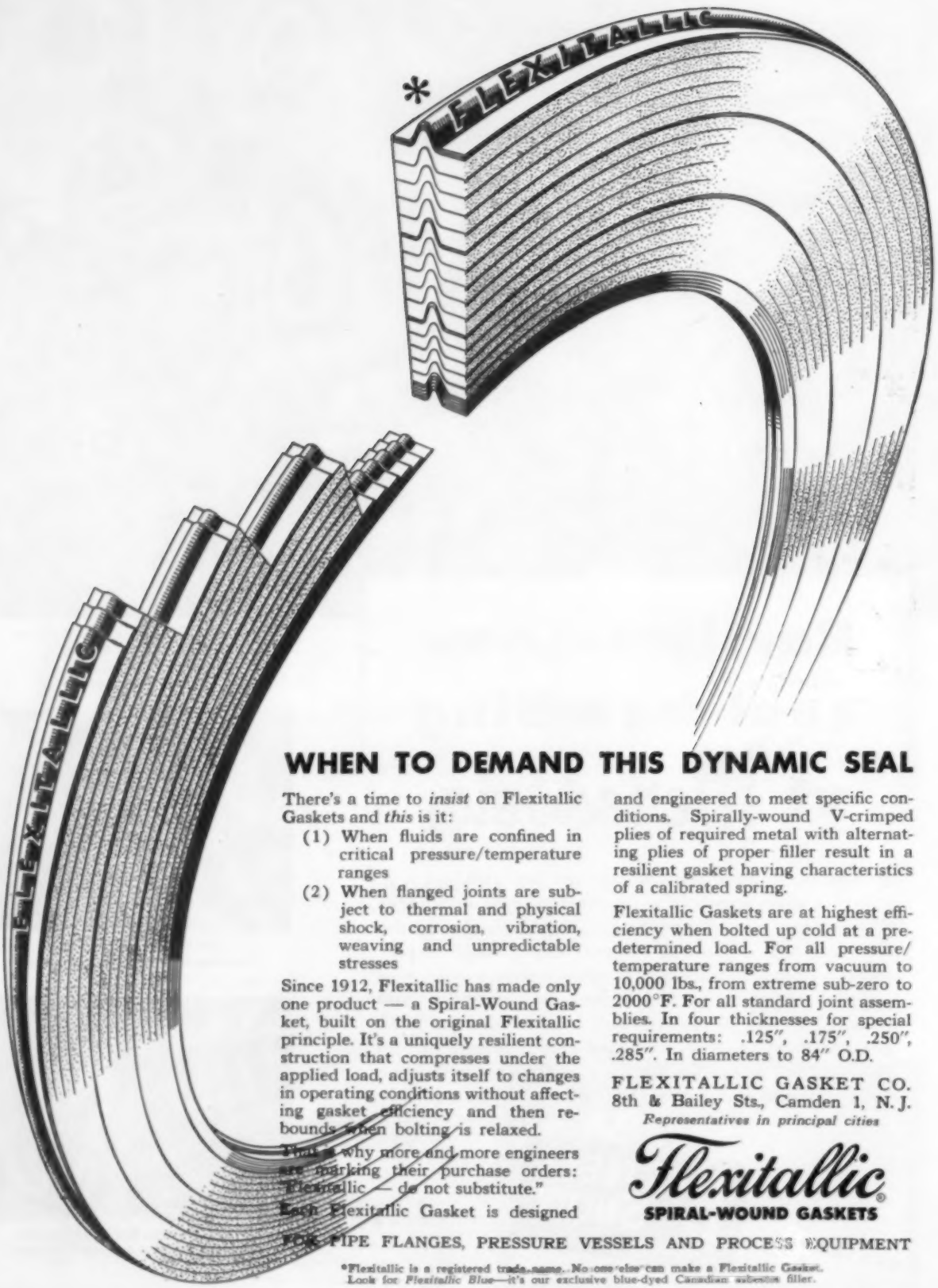

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Editorial

Where Now in Engineering Manpower?

Perspective is a quality most essential in a situation where frenzy appears to be gaining the upper hand. And that is just about the current state of engineering manpower. Government officials try to outdo one another in pointing out the ominous dangers of losing the technological manpower race, and industrial recruiters compete almost as vigorously for scientific and engineering personnel as their sales brethren compete for business. Even the respected *New York Times* used this headline approach in a prominent place on the front page of its Sunday edition of January 29: "Engineer Is King As U. S. Industry Vies For Talent".

But what is the ultimate solution and where is the sure future source of engineers and scientists? The individual, and specifically the youth who is making the important decision of choosing a lifetime vocation, is the key to the manpower problem. To gain this perspective, place yourself figuratively in the audience of the Winter General Meeting of the American Institute of Electrical Engineers in the ballroom of the Hotel Statler in New York City, and listen as Roger M. Blough, Chairman of the Board of United States Steel Corporation, paints this work picture of "The Challenge of America".

"Somewhere in this day's twilight there is a boy sitting alone. He may be your son or a neighbor's son. He is thinking about his most pressing obligation, what to do with his life, what to make of himself.

"Out of nowhere, perhaps, will come the realization that he will find personal growth and confidence and the full life if he can only make a plane that will fly better in the air, or a machine that will run better on rails; or if he can make a device to lessen human drudgery in the home, or build a home so beautiful and so full of human satisfaction that it will excel all that has gone on before.

"For this boy, a ship that sails the sea may be the answer, or the answer may lie in the insatiable demands for fuel from under the ground and for power to turn the wheels of industry. Or for him, a deep-seated satisfaction may come from learning and knowing that the unfathomable atom can be harnessed; that the re-alignment of nature's forces to do useful work is only at its beginning and that here he can find great usefulness.

"Somewhere in that young valiant mind struggling with its grave problem will emerge the image of men of science and men of engineering—men like you—who became what they are, not through compulsion, but of their own free will—not in the expectation of easy riches, but rather in the dedicated hope that their chosen career may afford them at least one fleeting moment of major achievement.

"That boy, though he may say little, will see in you, and the others like you, the builders of America. And when he sees that much, every thoughtful boy and every understanding boy will see a little more—something beyond what you have been able to show him. He will see himself grasping your work, building mightily upon what you have built. In what you have pioneered, he will see the great challenge of America for his own work and for his own life.

"When he does see, he will eagerly join your clan, mostly because of you. And your clan will thereby be greatly strengthened. You, in your own individual way, will thus have met, remarkably well, the ultimate challenge of personal freedom—the challenge of America."

The Never-Ending Search for Energy

Our attention has been called to the recent approval by the House and Senate for a $3,000,000 expenditure for a survey on harnessing the tides in the Bay of Fundy to be conducted by the International Joint Commission in United States-Canadian Waters. While it brings to mind the Passamaquoddy project of the middle thirties it also emphasizes the never ending search for energy sources. This search, fortunately, is widespread.

At the 120th ordinary General Meeting of the Société des Ingénieurs Civils de France held jointly with the Institution of Civil Engineers of Great Britain in London a year ago January, Professor R. Gibrat gave a highly informative lecture on tidal energy. This lecture pointed up many long range possibilities for drawing energy from those points, widely scattered around the globe, that enjoy favorable tides.

Similarly we noted a recent bulletin from the Stanford Research Institute reporting on the five-day meeting sponsored by S. R. I., the Association for Applied Solar Energy and the University of Arizona in November of 1955. This bulletin averred that those in attendance came away with the feeling that practical uses of solar energy are not too far distant. In addition we recall the Bell Telephone Laboratory report of a year or so ago on their solar battery which was held to have an efficiency of 11 per cent.

Lastly we have heard of the efforts in Great Britain to develop a hydrogen-oxygen fuel cell operating at 250 to 450 F and at pressures of 600 to 800 psi. The hydrogen and oxygen used as fuel, it is envisioned, would come from the electrolysis of water using purchased power from some low-cost outside source.

All of the above efforts are praiseworthy since they reflect a recognition of the seriousness of a problem that unless solved could well be calamitous to our way of life. The problem is not a dire one, certainly not now, but by the turn of the century, in year 2000 or so, it could well be. Any progress achieved today in fundamental research along the line of new energy sources can be likened to the "ounce of prevention" in the old adage.

Evaluation of Factors Affecting Heat Transfer in Furnaces*

By MURRAY GREYSON,† G. P. MAZIE,‡ J. W. MYERS,** R. C. COREY,†† and E. G. GRAF‡‡

Correlating the heat-absorption efficiencies of coal-burning equipment has been studied for many years with little more than a modicum of success. One of the major problems to such correlation has been the lack of precise furnace data. This paper describes the attempt at using statistics to correlate more reliable furnace data by means of the Broido, Hudson-Orrok, a modified Hudson-Orrok, Wohlenberg, and Hurvich correlations. Results suggest that information about flame temperatures, flame volumes, and emissivities and temperatures of flames and slag-ash-covered boiler-tube walls are necessary before precise correlations can be made.

THE combustion of fuels in furnaces has been, and for a great many years will continue to be, the major source of thermal energy for the production of electric power and for the processing of materials. Indeed, there are few commercial or industrial operations that do not employ some sort of furnace in either a primary or auxiliary capacity. Despite the long history of the use and development of furnaces, and their technological importance, furnace design still is highly empirical, owing to a lack of knowledge of the complex heat- and mass-transfer processes that occur within a combustion chamber. As with any technology that depends heavily upon empiricism, innovations are usually rare, and developments follow conventional lines until a high degree of perfection is achieved. Central-station boiler furnaces, for example, in which some 25 per cent of the nation's coal production is burned to generate steam for turbogenerators, have slowly evolved to a high degree of perfection by empirical means. It is highly improbable, however, that substantial improvements in dependability and performance, or reduction in capital and operating costs will come until there is better understanding of the nature of combustion and heat-transfer processes in flames and burning fuel beds, and the effects of these processes on the net heat transfer within the furnace cavity.

In the past 25 years, a great deal of both theoretical and experimental work has been done to elucidate the fundamental problems related to furnace design. This work, however, has been hampered by the great difficulty in isolating the individual processes that are related to combustion and heat transfer, and by poor coordination between combustion research and combustion engineering, especially from the standpoint of applying the results of the type of research that is presently being done. Moreover, the experimental procedures for measuring physical and chemical properties of flames and hot gases are difficult and subject to errors of unknown origin. For example, where nonluminous flames are concerned, it is possible to calculate the radiant-heat transfer to various parts of the furnace quite accurately, if the temperature, composition, and dimensions of the flame are known. Radiation from a luminous flame, however, is influenced by the presence of radiating particles in the flame, the effects of which are very difficult to evaluate experimentally. Because of these difficulties, the amount of luminous flame radiation is generally approximated by computing the theoretical nonluminous component of the flame, and then multiplying it by a relatively large factor, the magnitude of which depends upon experience with the types of fuel and furnace being used. This technique is necessary because, although it is known that carbon and ash particles in a flame markedly increase radiation from the flame and that size and concentration of the particles determine the contributions of the particles to the emissivity of the flame, information is meager, except for very simple systems, on mechanisms of particle formation, methods of characterizing the size and concentrations of particulate matter, and the quantitative effects of these factors on the radiation characteristics of clouds of particles.

Although it is generally believed that small-scale experiments in connection with luminous-flame radiation cannot provide the dynamic similitude that is necessary for the generalized correlation of flame variables, especially with regard to the aerodynamic factors that affect the size and shape of flames and the amount of recirculation of spent gases, the optimum scale for experimental work is not known, and probably will not be known until sufficient data have been obtained from furnaces of various sizes. Data from full-scale furnaces are of immediate practical value if they are sufficiently precise and comprehensive, and may be used to develop empirical relationships between the operating variables and the furnace heat-absorption efficiency. Such relationships, however, are necessarily limited in scope, and do not achieve the ultimate objective in this field of research, that of relating flame radiation to heat absorption by a general equation. Moreover, experiments on full-scale equipment are limited in the range of operating variables that can be studied, the number and location

* Presented at 75th Annual Meeting of American Society of Mechanical Engineers, Chicago, Ill., November 1955.
† Physical Chemist, Combustion Section, Bureau of Mines.
‡ Chemical Engineer, present address—Armstrong Cork Co.
** Chief, Combustion Section, Bureau of Mines.
†† Chief, Division of Solid Fuels Technology, Bureau of Mines.
‡‡ Chemical Engineer, Present address—Vienna (Wien), U. S. Zone, Fluchtgasse 8, Austria.

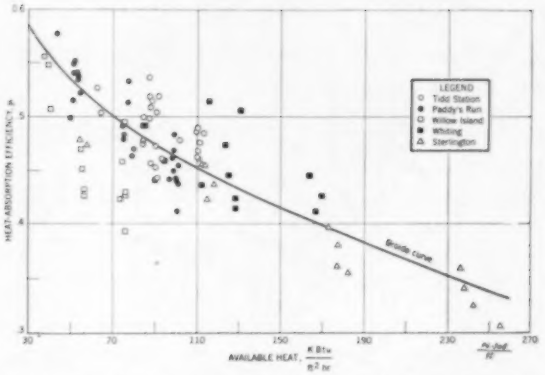

Fig. 1—Correlation of experimental heat-absorption efficiencies by a Broido curve

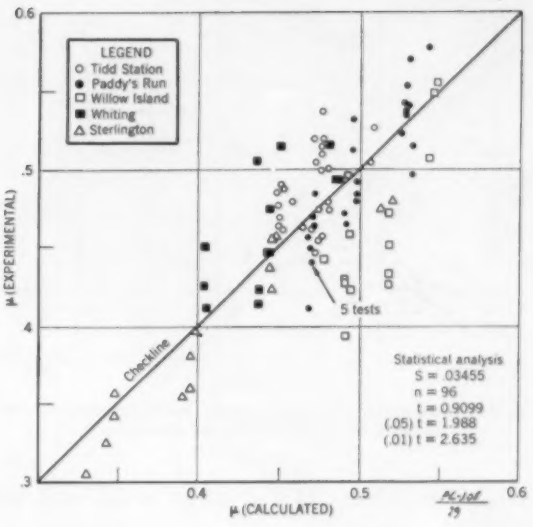

Fig. 2—Correlation of predicted efficiencies and experimentally determined efficiencies (Broido)

of points where observations and measurements can be made, and the constancy of operating conditions within a given time interval. Notwithstanding these difficulties and limitations, full-scale experimentation is an essential phase of research in this field.

A considerable amount of experimental data has been obtained from a wide variety of furnaces over a period of some 35 years, and numerous empirical equations have been proposed to relate the heat-absorption efficiency of a furnace to the operating variables of that furnace, such as percentage of excess air and heat-release rate. Attempts have also been made to correlate these data by means of such theoretical equations as the Stefan-Boltzmann law. However, due to a lack of precision in the collection of data, or to the inadequacies of the equations, none of these relationships have been found to be satisfactory for describing the data. Between 1948 and 1953, however, the United States Bureau of Mines, in cooperation with the Special Research Committee on Furnace Performance Factors, of the American Society of Mechanical Engineers, published a series of papers covering details of experimental studies made on five industrial boiler furnaces (1–5)[1] the data from which were believed to be more reliable than much of the previous furnace data. These studies included work on three pulverized-coal-fired (Paddy's Run, Tidd Station, and Willow Island), one spreader-stoker-fired (Whiting), and one gas-fired furnace (Sterlington), and were made for the purpose of evaluating the factors affecting the heat-absorption efficiencies of these furnaces. In 1953, the Committee decided that before any further experimental work was done the data from these installations should be analyzed to determine whether or not a generalized correlation of furnace heat-absorption efficiency could be obtained in terms of the operating parameters of the furnace. Accordingly, the Bureau of Mines initiated a detailed study of the data to determine whether any of a number of correlations that have been proposed could be used to describe these data. Although the analysis is not yet complete, some significant limitations of the data that, it is believed, can act as guides for future experimental work have become evident.

This paper is, therefore, a progress report and will cover the work that has been completed to the present time.

Examples of Previous Work

Hudson, (6) in 1890, attempted to relate the heat transmission in a furnace to the radiant-surface area, the rate at which the fuel was consumed, and the air-fuel ratio, and proposed the following empirical equation for the heat-absorption efficiency of the furnace:

$$\mu = \frac{XF}{Q} = 1 - \frac{A}{A + 45F} \qquad (1)$$

where μ is the heat-absorption efficiency, X is the rate of heat transmission per hour per square foot of radiant wall surface, Q is the available heat per pound of coal fired, F is the number of square feet of radiant wall surface per pound of coal fired per hour, and A is the air-fuel weight ratio.

This equation was not universally applicable, and in 1925 was modified by Orrok (7) as follows:

$$\mu = \frac{X}{C_r Q} = \frac{1}{1 + (A\sqrt{C_r}/27)} \qquad (2)$$

where μ, X, and Q are defined as before, and C_r is the reciprocal of F.

At the same time that Orrok suggested his empirical modification of Hudson's equation, Broido (8) presented an empirical curve that was obtained from the average data of six boiler stations, and which related available heat per unit area of radiant surface to the heat-absorption efficiency of the furnace. Broido claimed that most existing data could be fitted to the curve with a precision of ± 10 per cent.

Empirical correlations such as the Hudson, Hudson-Orrok and Broido techniques supplied information about the overall performance of a furnace, but gave no information about operating variables such as flame emissivities, flame temperatures, cold-wall temperatures, flame volumes, and specific burning rates of fuel. Moreover, the effects of ash and slag on the emissivity and

[1] Numbers in parentheses refer to Bibliography at the end of the article.

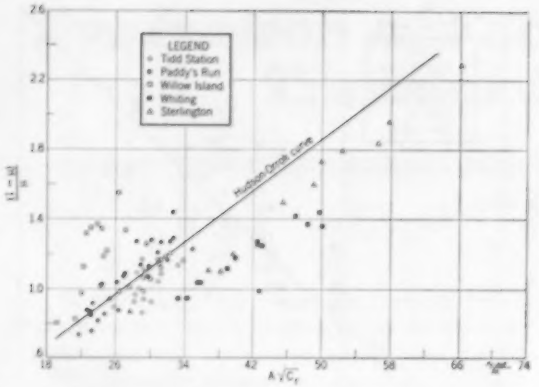

Fig. 3—Correlation of experimental heat-absorption efficiency by a Hudson-Orrok equation

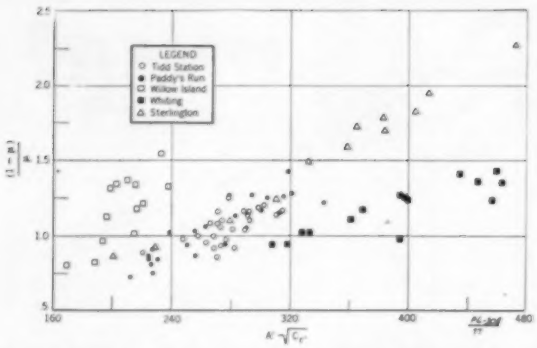

Fig. 4—Correlation of experimental heat absorption efficiency by a modified Hudson-Orrok equation

temperatures of the cold wall of the furnace were not considered.

One of the first attempts to place furnace data on a fundamental basis was made by Wohlenberg and his associates (9–12) who, since 1925, have published a series of papers that relate various effects within a furnace to the operating parameters of the furnace. The approach used by these investigators was to apply certain heat-transfer equations to furnaces having specific assumed characteristics, and to calculate the theoretical heat-absorption efficiencies for these assumed furnaces. Experimentally determined furnace heat-absorption efficiencies were then compared with the calculated efficiencies when individual operating parameters were varied. The corrections to the theoretical efficiencies were then plotted as functions of the level of the operating parameters, and a series of factor-curves was developed. By applying the proper set of factors to the calculated efficiency, it was then possible to calculate the heat-absorption efficiency of a real furnace. The equation used by Wohlenberg for the application of correction factors was

$$\mu = \mu_0 \frac{i = 8}{\perp = | K_i} + C \qquad (3)$$

where μ is the actual furnace heat-absorption efficiency; μ_0 is the efficiency of the assumed furnace, K_i are corrective factors related to furnace volume, fraction of total furnace wall that is cold, heat-liberation rate, per cent excess air, heating value of fuel, size of fuel particle, effective radiant-heating surface, and combinations thereof; and C is a factor related to preheated air temperature.

Other fundamental approaches have also been tried.

By a dimensional analysis of the furnace system, Hurvich (13) developed the following equation:

$$B_0 = \frac{BQ\mu}{HC_r T_i^4 (1 - \Theta_0)} \qquad (4)$$

where μ is the furnace heat-absorption efficiency, B_0 is a modified Boltzmann number, B is the fuel-consumption rate, Q is the heating value of the fuel, H is the radiant-wall area, C_r is the overall emissivity of the combustion chamber, T_i is the adiabatic flame temperature, and Θ_0 is the dimensionless ratio of the flue-gas temperature at the furnace outlet to the adiabatic flame temperature, [the term B/H in this equation is equal to C_r in the Hudson-Orrok equation, equation (2)]. Hurvich showed by experiment that Θ_0 and B_0 were related by an equation of the form

$$\Theta_0 = \frac{B_0^{\alpha}}{1 + B_0^{\alpha}} \qquad (5)$$

where α is a constant equal to 0.6 for coal-fired furnaces.

Konokov (14) improved upon Hurvich's equation by suggesting the heat-balance equation

$$Z_0^4 P_i \left[\frac{T_2}{T_i}\right]^4 + \frac{T_2}{T_i} - 1 = 0 \qquad (6)$$

where

$$P_i = \frac{C_0 \left(\frac{T_i}{100}\right)^3 H}{100 B V C_p} \qquad (7)$$

$$Z_0 = \frac{T_2}{T_1} \sqrt[4]{\epsilon} \qquad (8)$$

T_i is the adiabatic flame temperature, T_1 is the temperature of the flame surface, T_2 is the flue-gas temperature at the furnace outlet, B is the fuel-consumption rate, V is the volume of flue gas per unit weight of fuel, C_p is the average specific heat of the flue gas, C_0 is the Stefan-Boltzmann constant, H is the radiant surface area of the furnace, and ϵ is the emissivity of the firebox.

The equations cited above are just a few examples of the many attempts that have been made to correlate furnace performance data and operating parameters, and have been selected to illustrate the variety of approaches that have been used in this work. It is sufficient to state here that the lack of precision of data collected in the past has prevented a comprehensive evaluation of the applicability of most of these correlations.

Procedures

The analyses made by the Bureau of Mines of the data from the five boiler stations were divided into three separate steps. The first analysis was concerned with the general correlation of all of the data as a group with any one or all of five correlations: the Broido, the Hudson-Orrok, a modified Hudson-Orrok, the Wohlenberg, and the Hurvich equations. In this phase, limited statistical techniques were used to compare heat-absorption effi-

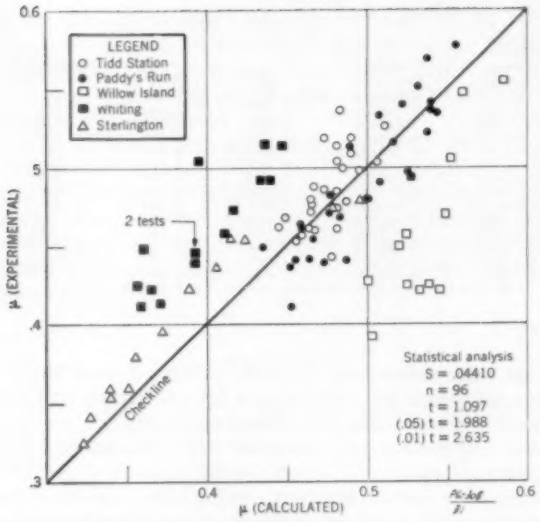

Fig. 5—Correlation of predicted efficiencies and experimentally determined efficiencies (Hudson-Orrok)

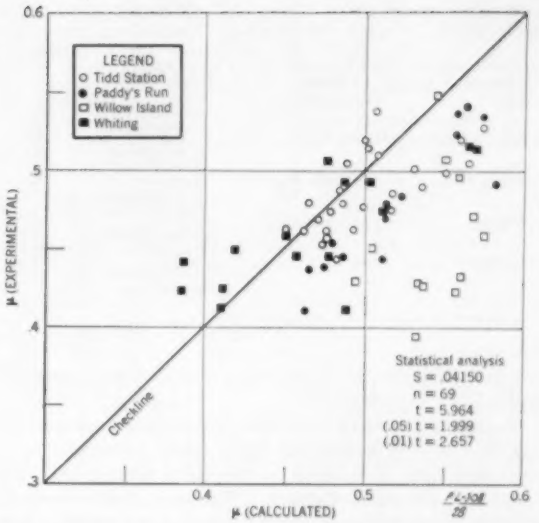

Fig. 6—Correlation of predicted efficiencies and experimentally determined efficiencies (Wohlenberg)

ciencies that were determined experimentally and those that were calculated or predicted from the proposed correlations. Accordingly, it was possible to determine whether or not the differences that were observed were statistically significant. The statistical method that was used in this and the other analyses is illustrated in the Appendix.

The second analysis was concerned with individual correlations and consisted of fitting the experimental data from individual stations to these proposed equations, and determining the significance of any differences that were observed between experimental efficiencies and those calculated from the equations. This phase was found to be necessary because in some instances the overall data were very adequately described by an equation, whereas data from individual stations differed appreciably from those calculated by the equation.

The third analysis was an attempt to find a generalized correlation that would describe the furnace data both as a group and individually by station. This phase of the work, of course, depended upon the results of the previous phases.

To date, most of the data correlation has been completed. The data from all five stations have been compared with the Broido, Hudson-Orrok, modified Hudson-Orrok, and Wohlenberg relationships. In addition, the data from the gas-fired furnace have been plotted, by means of estimated adiabatic flame temperatures, in the manner suggested by Hurvich and Konokov. It was not possible to plot data from the coal-fired units by means of the latter two equations because no comparable data on coal-flame temperatures are yet available. However, calculations of these flame temperatures are presently being done, and as soon as these data are available, the comparisons will be made.

Results

Fig. 1 shows the 96 furnace tests from the five stations plotted according to Broido's curve, which is shown on the figure. To show better the relationship between the predicted and experimental efficiencies, the same data have been replotted around a "check line" in Fig. 2.

The spread of points around the line is characterized by an average difference of −0.0028 and a standard deviation of 0.03455. If the average difference between the predicted and experimental heat-absorption efficiencies is assumed to be due to a random distribution of experimental errors, and this average is compared with zero by means of the Student t-test, no significant difference is found between the predicted and experimentally-determined efficiencies. The calculated t value is equal to 0.9099, and compares favorably with values from a double-sided t-table of 2.635 and 1.988 per the 1- and 5-per cent probability levels, respectively.

The experimentally determined heat-absorption efficiencies are plotted in Fig. 3 according to the Hudson-Orrok equation, together with the curve obtained from the equation. In Fig. 4, the same data are plotted according to a modified Hudson-Orrok equation in which fuel consumption is expressed as thousands of Btu of available heat per square foot of radiant heating surface, and the air-fuel ratio as pounds of air per thousand Btu of available heat.

The difference between the predicted efficiencies calculated from the Hudson-Orrok equation and experimental results are shown in Fig. 5, in which the check line technique was used. The plot is characterized by a mean difference of 0.00494, and a standard deviation of 0.0441. The calculated value of t of 1.097, when compared with table values of 2.635 and 1.988 for the 1- and 5-per cent probability levels, respectively, indicate that there is no significant difference between the calculated and the experimentally determined efficiencies.

Fig. 6 shows the experimental data plotted against the efficiencies calculated by the Wohlenberg equation. In this plot, the mean difference of −0.02984 and the standard deviation of 0.04150, and the t value for 69 test points (gas-fired furnace data could not be used) of 5.964 indicate that the Wohlenberg equation cannot be used to describe these furnace data. The table values

TABLE 1—STATISTICAL TESTS OF FURNACE DATA

Station	Type of Firing	Type of Correlation	No. of (n)	Average Difference between Efficiencies	Standard Deviation	t =	t at 95%	Significant Variation
Tidd	Pulverized fuel	Broido	26	+0.016115	0.023090	3.621	2.060	Yes
		Hudson-Orrok	26	+0.010884	0.019443	2.918	2.060	Yes
		Wohlenberg	26	−0.015000	0.025456	2.999	2.060	Yes
Paddy's Run	Pulverized fuel	Broido	28	−0.006714	0.024244	1.4654	2.052	No
		Hudson-Orrok	28	−0.005110	0.020780	1.3010	2.052	No
		Wohlenberg	15	−0.031800	0.019139	6.4350	2.145	Yes
Willow Island	Pulverized fuel	Broido	13	−0.049770	0.036255	4.9400	2.180	Yes
		Hudson-Orrok	13	−0.071600	0.035160	7.3430	2.180	Yes
		Wohlenberg	13	−0.084920	0.042450	7.2140	2.180	Yes
Whiting	Spreader-stoker	Broido	15	0.022067	0.031721	2.6942	2.145	Yes
		Hudson-Orrok	15	0.067466	0.017869	16.1822	2.145	Yes
		Wohlenberg	15	−0.005867	0.038118	0.5961	2.145	No
Sterlington	Gas	Broido	14	−0.015857	0.017974	1.0439	2.160	No
		Hudson-Orrok	14	0.018071	0.015340	1.3940	2.160	No
		Wohlenberg		This type of correlation not applied to gas-fired furnaces.				

of t for the 1- and 5-per cent probability levels are 2.657 and 1.998, respectively.

Similar analyses of data from individual stations were also made. Experimental data were compared with predicted data from each of the three equations. The results are shown in Table 1. No significant differences were observed between Paddy's Run data, and the data calculated from the Broido and Hudson-Orrok equations. These two techniques could also be used to describe the data from the gas-fired unit at Sterlington. The Wohlenberg equation, however, was only satisfactory for describing the spreader-stoker data from Whiting. On the whole, no one correlation described the data from all of the stations taken individually, and in two instances, Tidd Station and Willow Island, none of the correlations were adequate.

The Hurvich and the Konokov equations, both involving adiabatic flame temperatures, were used to correlate the data from the gas-fired unit at Sterlington. These data are plotted by a Hurvich equation (equation (5)) in Fig. 7. The parameters of the plot are θ_0 and $B\mu/[T_1^4(1-\theta_0)] \times 10^{-6}$, which have been defined in a previous section of the paper. The parameter k in Fig. 7 is equal to Θ/HC_1 which is a constant for the furnace. In both instances, very satisfactory correlations of the data were obtained, despite the estimated flame temperatures that were used.

Discussion and Conclusions

As demonstrated by the Sterlington data, the correlation of furnace data from clean-walled combustion chambers may be obtained in many ways. The small variations that are observed can be attributed to a number of factors such as changes in flame shapes and volumes with load, excess air, and burner arrangement. As soon as the furnace walls become covered by ash and slag, however, the differences between predicted and experimental values for heat transfer become larger, and the whole problem becomes extremely complex. Factors that are present and influence the operation of coal-fired equipment, and which are not present in gas-fired equipment include the heat conductivity, and the temperature and emissivity of the flame and the ash and slag coating the furnace-wall tubes.

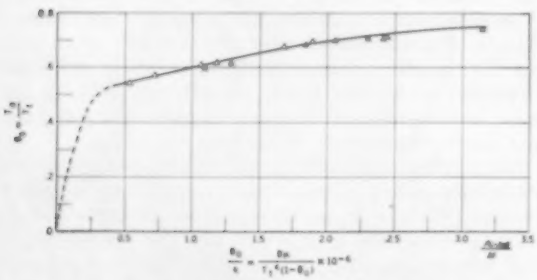

Fig. 7—Correlation of Sterlington heat-absorption efficiency by a Hurvich equation

Although an attempt to correlate furnace data from coal-fired equipment by means of one or more of the fundamental flame-temperature relationships will be attempted, it is doubtful that improved correlations will be obtained. This conclusion is suggested by the fact that most fundamental relationships involve a radiation variable related to the temperature of the furnace wall. In most fundamental furnace expressions the radiation from the furnace wall back to the flame is considered to be negligible and is neglected. For clean-walled furnaces, such as Sterlington, this assumption is valid since the temperature of the walls and boiler tubes are in the range 700–800 F., as compared to the flame temperature of approximately 3000 F. When, however, the wall is covered by a coating of ash and slag, which may vary in temperature from 700 to 2000 F., the assumption is not valid, and may not be made. Some attempts have been made to allow for this slag-ash factor. Mullikin (15), as well as Mumford and Bice (16), have suggested methods that can be used to correct radiant heat-absorbing surface. These techniques, however, involve very many assumptions, and do not allow for the temperature of the slag coating.

Recommendations

To evaluate properly the heat-transfer in a furnace, it is necessary to know flame temperature and flame emissivities, and the effects on these factors of such variables as flame shape, flame length, type of fuel, degree of mixing of fuel and air, and per cent excess air. It is possible that such information can be obtained by designing experimental furnaces as sectionalized calorimeters, such is being done at the International Flame-Radiation Trials at Ijmuiden, Holland. However, the experimental problems are numerous and complex and will only be solved by the application of experimental experience.

In addition to information on flames, future experimental work should be directed at obtaining the radiation and conductivity characteristics of the slag and ash coatings of furnace walls, as well as the fraction of wall area covered by ash and slag. In large-scale industrial experimentation, some indications of these character-

istics may be obtained by measuring slag and ash temperatures as well as tube-metal temperatures. These temperatures are necessary if the reradiation from the wall back to the flame and the heat transfer to the boiler tubes is to be evaluated.

The third, and perhaps most important recommendation is, that all future work be planned so that all data can be interpreted statistically, and an estimate of the precision of the measurements be made. This approach would probably require a factorially designed program to facilitate the gathering of the most meaningful data with least amount of effort.

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APPENDIX

Predicted heat-absorption efficiencies were compared statistically with values that were determined experimentally to determine whether or not the differences between values were due to a random distribution of experimental errors. The method is based on the theorem of statistics that states that if $\bar{X}$ and s are estimates of the mean and standard deviation of a random set of n samples taken from a normally-distributed universe with a true mean equal to m and a standard deviation equal to ρ, the t-ratio, which is defined by the equation

$$t = \frac{(\bar{X} - m)\sqrt{n}}{s} \tag{9}$$

will exceed the value A only B times out of a 100 at the B-per cent probability level. If t is found to be greater than A, it is concluded that $\bar{X}$ is not an estimate of m, and that $\bar{X}$ and m are not from the same universe. This is commonly called the null hypothesis.

In the actual comparisons, the statistical tests were used to determine whether it was reasonable to assume that the average difference,

$$\frac{\sum_n (\mu_{exp} - \mu_{calc})}{n} \tag{10}$$

was due to experimental error and that no real difference between calculated and experimentally determined efficiencies existed. For the particular case in question, equation (8) becomes

$$t = \frac{\left[\left(\frac{\sum_n (\mu_{exp} - \mu_{calc})}{n}\right) - 0\right]\sqrt{n}}{S} \tag{11}$$

The 1- and 5-per cent probability levels were chosen to determine the significance of t.

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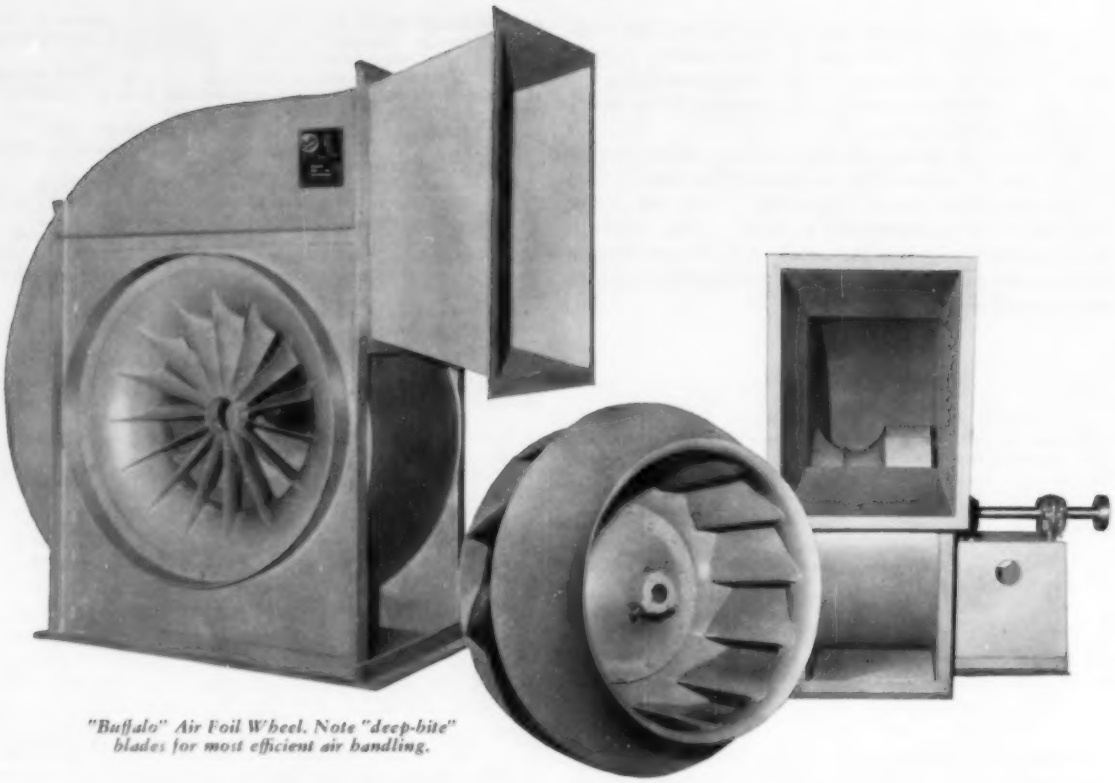

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Fuel Elements for Nuclear Reactors*

By JOHN B. ANDERSON

Combustion Engineering, Inc.

A general discussion is presented of the basic requirements for fuel elements for nuclear reactors and of the heat transfer characteristics affecting the selection of a fuel element design. This is followed by a presentation of typical fuel elements along with a discussion of their potential performance and applicability in line with the basic requirements and heat transfer factors discussed earlier.

IN order to utilize the heat of the fission process for the generation of power, the fissionable material or fuel must be formed into a unit of proper geometry to permit control of the process and safe removal of the heat generated. This unit is the reactor core, and the fuel element components of this core are one of the major concerns in the development of nuclear power.

Basic Requirements for Fuel Elements

A reactor core for the generation of power is first of all a heat transfer design with the prime purpose of producing heat at the maximum possible rate. This heat must be removed from the core and transferred to the steam generator in the most efficient manner. Important as they may be, all other considerations are primarily limitations on the achievement of an optimum heat transfer design. It is necessary to consider all facets of the design and the optimum combination is arrived at by a careful compromise of the heat transfer design with the physics, mechanical design and metallurgical factors.

Generally the size of a reactor core is determined by the volume necessary to contain the number of fuel elements providing the specified heat transfer area and by the required volume of the coolant and moderator which is a function of the type of reactor under consideration. The exception occurs in the case of very small cores where critical mass limitations, rather than heat transfer requirements, may dictate the size.

If the fuel elements are finely divided, there will be more heat transfer surface per unit of core volume and per pound of fuel; however, the fabrication cost will be greater. Low fabrication cost is always a consideration, but it is of utmost importance in a reactor for low cost power generation. Therefore, designing fuel elements for economic electric power generation requires a somewhat different basis than designing fuel elements for compact, high performance military power plants.

A number of basic considerations apply to all fuel elements, as follows:

1. Geometry
   a. A form giving a high surface to volume ratio is desired.
   b. The form must be such that the coolant can remove the heat with maximum efficiency from the entire surface of the fuel element.
   c. High pressure drop forms are acceptable only when accompanied by a proportionately greater gain in heat transfer rate.
2. The fuel element must be of the simplest design consistent with the performance demanded.
3. Mechanical stability is essential and must be balanced with the heat transfer demands for thin elements. Mechanical instability and the resulting distortions are produced by structural loads, vibrations, pressure differences and thermal stress.
4. The minimum amount of structural material is desired for fuel element support within the core. Thus a fuel element that is self-supporting is the optimum for this consideration.
5. Cladding is generally required for corrosion protection and/or fission product containment. Since it is possible for some of the best corrosion resistant materials to be eliminated from consideration by nuclear limitations, the maximum allowable surface temperatures may be limited by corrosion.
6. Ease of fabrication and low cost are desirable. These usually go together. Simple geometries need to be fully exploited for this reason, and also because they may more easily lend themselves to mass production with even greater savings in cost.

Heat Transfer Characteristics Affecting Selection of Fuel Element Design

The greatest efforts toward improved heat transfer performance should be directed to the water and gas cooled reactors, as opposed to liquid metal cooled applications, since a greater potential gain exists in these cases.

The high conductivity and low film drop of sodium (the commonly used liquid metal today) precludes the necessity for an extensive design effort to improve the heat transfer coefficient. The primary factor in determining sodium coolant flow rates is usually the allowable temperature rise as limited by thermal stresses and the high temperature strength of the metals used. Obviously, simple shapes and assemblies with minimum pressure drop and low fabrication cost are desired.

For water and gas cooled applications, improved heat transfer rates are obtained by increased turbulence over the heat transfer surface. This may be produced by a high coolant velocity in parallel flow or by interrupted surfaces such as cross flow over tube banks. A high heat transfer coefficient is obtained for interrupted surfaces

* Contributed by American Society of Mechanical Engineers and presented at the Nuclear Engineering and Science Congress sponsored by Engineers Joint Council, Dec 12–16, 1955, at Cleveland, Ohio.

at a lower coolant flow rate than for continuous surfaces; thus pumping power is usually not adversely affected.

In parallel flow the heat transfer coefficient is generally determined by the Colburn equation:

$$\frac{h\,D_e}{k} = 0.023\left(\frac{D_eG}{\mu}\right)^{0.8}\left(\frac{\mu\,c_p}{k}\right)^{1/3} \qquad (1)$$

where

h = Coefficient of heat transfer between coolant and surface—Btu/(hr)(sq ft)(F)
D_e = Equivalent diameter, feet
G = Mass velocity lb/(hr)(sq ft)
μ = Viscosity of fluid, lb/(hr)(ft)
c_p = Specific heat at constant pressure, Btu/(lb)(F)
k = Thermal conductivity of fluid, Btu/(hr)(sq ft)(F/ft)

For cross flow over tube banks the correlation developed by Kays and Lo at Stanford University[1] agrees very closely with that of other investigators. When more exact information is lacking, this may be used as an approximation for calculating interrupted surfaces that closely resemble tube banks.

$$\left(\frac{h}{c_pG}\right)\left(\frac{c_p\mu}{k}\right)^{2/3} = C_n\left(\frac{D_eG}{\mu}\right)^{-0.4} \qquad (2)$$

where

$\frac{h}{c_pG}$ = Stanton dimensionless group

$\frac{c_p\mu}{k}$ = Prandtl number

$\frac{D_eG}{\mu}$ = R_e = Reynold's number

C_n = An arrangement factor for tube bank configurations.

Dividing equation (2) by equation (1) above and solving for the ratio of heat transfer coefficients results in the following relationship:

$$\frac{h_c}{h_p} = \frac{C_n}{0.023}\,\frac{1}{(R_e)^{0.2}} \qquad (3)$$

If the fuel elements are spaced within 2 to $2^1/_2$ diameters center to center, the arrangement factor C_n may be taken as 0.425. Equation (3) then reduces to:

$$\frac{h_c}{h_p} = 18.5\,(R_e)^{-0.2} \qquad (4)$$

For a Reynolds number of 10,000 the coefficient for cross flow (h_c) is greater than the coefficient for parallel flow (h_p) by a ratio of almost 3 to 1 (2.96 to 1); at a Reynolds number of 100,000 it is 85 per cent greater, and at a Reynolds number of 500,000 it is 33 per cent greater. This decreasing ratio is obtained at the expense of high velocity and resulting high coolant flow rates for the parallel flow case. For the highest Reynolds number (500,000) coolant velocities of 35–40 ft/sec are required for parallel flow.

The fuel element geometry will provide either disconnected parallel channels, connected parallel channels or a discontinuous flow path through the core. In disconnected parallel channels, adverse effects are cumulative along the channel. In discontinuous flow paths the effect of local hot spots stays local, since the coolant mixing averages out the local effects on the coolant temperature rise. The effect will be the same for the connected parallel channels if adequate coolant mixing between channels occurs.

[1] W. M. Kays and R. K. Lo, "Basic Heat Transfer and Flow Friction Design Data for Gas Flow Normal to Banks of Staggered Tubes by Use of a Transient Technique," Stanford University Technical Report No. 15, August 1952.

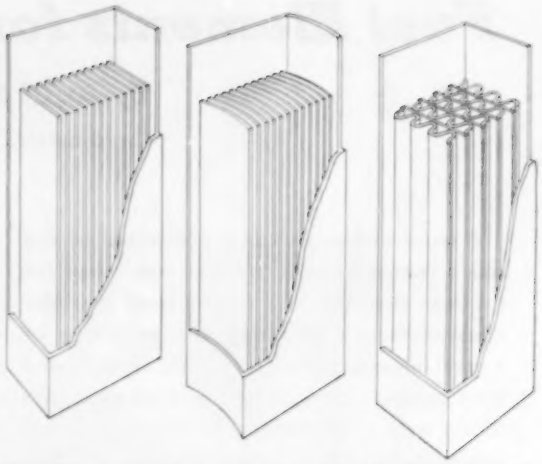

Fig. 1—Flat, curved, corrugated and flat (for figures reading left to right) plate type fuel elements

In order to evaluate various fuel element designs from the heat transfer standpoint, potential hot spots and their effect on film drop and coolant temperature rise along the hottest path must be considered. "Hot spot" factors that limit the heat transfer design of a reactor core are the result of the following conditions:

1. Local concentration of fissionable material. Variations in fuel thickness as well as fissionable material concentration are factors to be considered.
2. Cladding tolerances or eccentricity of fuel section.
3. Coolant passage tolerances.
4. Warpage of fuel elements or other flow restrictions.
5. Non-uniform flow distribution.
6. Variation of heat transfer coefficient and thermal conductivity from experimental data. (Thermal conductivity for some of the materials under consideration is not always well established.)

A fuel element that can be inspected with simple and reliable non-destructive tests will permit higher heat transfer performance with maximum reliability, since many of the above factors may be minimized.

Fuel Element Designs

Innumerable geometries can be conjectured for fuel elements; and by looking over designs suggested since the advent of the nuclear reactor, it appears that almost all conceivable shapes, arrangements and combinations have been proposed. There emerges from this mass of ideas a few basic geometries that are being applied to most reactors today. Recently, a few really worth-while designs that are simple but real innovations have appeared and should merit a great deal of consideration.

A number of such fuel element designs that may be used for power reactors are shown in Figs. 1 through 8. Basic designs in use today are shown along with new ideas. There are certainly other ideas that may be used; however, the designs shown represent a general cross-section.

Plate Type Elements

Plates may be flat, curved, or combinations of flat and corrugated, as shown in Fig. 1. The surface to volume ratio is $2/t$, where t is the thickness of the plate.

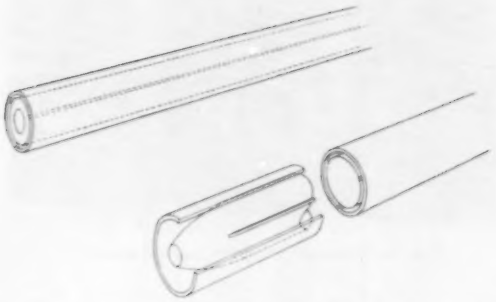

Fig. 2—Cylindrical fuel elements, rods and tubes

The edges of the plate are usually not available for coolant flow and are not included. This ratio is still on the high side since the effective heat transfer area is that inside the edge cladding. The edge cladding may be heavier than the side cladding to provide part of the structural material for support of the plates. Structural supports in the form of side and end plates are required to hold the fuel plates in proper relation to each other.

Wide, thin plates give maximum heat transfer surface per unit volume of fuel; however, they may become mechanically unstable and resulting vibrations or distortions can produce failure of the elements. Curved plates, or combinations of flat and corrugated plates, improve the stability of wide plates.

These fuel element arrangements form disconnected parallel flow channels with a relatively low pressure drop even at high coolant velocities. The deleterious heat transfer effects occurring at points along a continuous channel with no mixing between channels are cumulative. Close manufacturing tolerances can produce "hot spot" factors of considerable magnitude. For example, a 1/8-inch wide water channel formed by plates having a ± 0.002 inch overall thickness tolerance and a spacing tolerance of ± 0.005 inch may have a minimum width 11 per cent less than the nominal design value. To this flow reducing effect must also be added a factor for warping which can reduce the flow through this channel to an additional extent.

The core design must be predicated upon the most adverse combination of tolerances along the hottest channel. Orificing at the inlet end to minimize the effects of tolerances and warping on flow distribution may be desirable for low pressure drop cores. This may be used to additional advantage by distributing the coolant flow to compensate for the power variation across the core.

A high coolant velocity is required to obtain a high heat transfer coefficient. The resulting high coolant flow rate produces a considerable pumping power requirement even with the relatively low pressure drop.

Cylindrical Fuel Elements

The surface to volume ratio of a cylinder is $4/d$, where d is the diameter of the cylinder. This is considerably higher than for plates and becomes even higher for tubes where the ratio is $4/(d_2-d_1)$, where d_1 = inside diameter, d_2 = outside diameter.

Generally, it is only the ends of these types of elements that are not available for heat transfer surface. This is a small fraction of the total surface, and thus has not been included in the above ratios.

A single long rod, or tube, or a number of short rods, or tubes, placed in a concentric tube as shown in Fig. 2 provides the same disconnected parallel flow channel and heat transfer limitations of the plate type fuel elements.

As cylindrical elements are reduced in diameter to increase the heat transfer area, they become less stable and the problem of support and proper spacing becomes an integral part of the design. A bundle of slender rods having fine wire wound in helical fashion around each to provide support and spacing between adjacent rods is shown in Fig. 3.[2] This bundle may be fitted into a circular or hexagonal tube. The reactor core then consists of a cluster of such sub-assemblies.

The continuous mixing of the coolant along the flow path, partially induced by the helically wound wires, averages out the effect of local hot spots on the coolant temperature rise and thus the hot spot effects remain local. The hot spot produced by the wire wound around each element is small and the induced turbulence resulting in a higher local heat transfer coefficient will partially compensate for it.

Reduced to even smaller diameters, the cylindrical element becomes a wire. The design shown in Fig. 4[3] consists of crossed wire grids. The elements become self-supporting as is necessary for optimum design of all thin fuel elements in order to keep the amount of structural support material low. The figure shows a

[2] Proposed by M. Treshow, Argonne National Laboratory.
[3] Proposed by J. B. Anderson, while at Argonne National Laboratory.

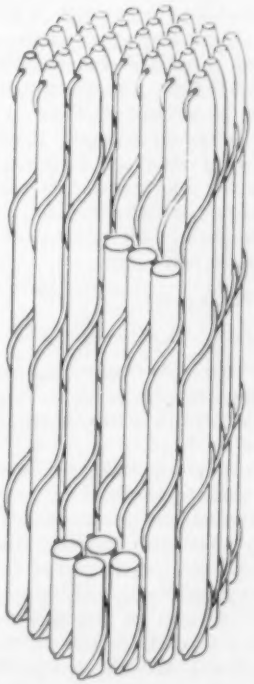

Fig. 3—Cylindrical fuel elements, slender rods

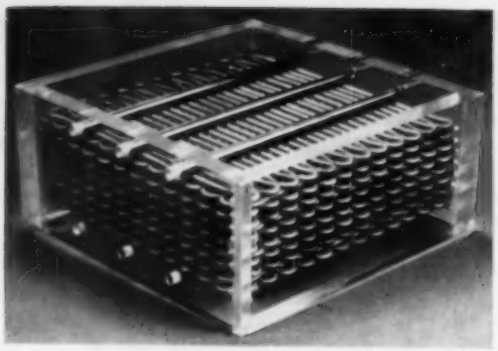

Fig. 4—Cylindrical fuel elements, wires

model of an assembly of grids clamped in a square or rectangular box. The ends of the wires are formed to a large radius bend to provide spacing between adjacent wires. If the wires are brazed at the contact points, this is not necessary. All surfaces of the element are available to coolant flow with the exception of limited cooling around the contact points. The element is simple, easily formed and easily assembled, thus lending itself to mass production techniques. If the grids are not brazed at the contact points, a box structure and means of clamping the grids is required as shown in the model of Fig. 4.

The cross flow arrangement results in high heat transfer rates at moderate coolant flow but high pressure drop. The high turbulence produces a high pressure drop; however, the scrubbing action on the surfaces of the wire, including the back surface, results in a high heat transfer coefficient.

The surface temperature of the wires is affected by the variation in heat transfer coefficient which occurs around the perimeter of a cylindrical element in cross flow and by the blanketing effect at the contact points of the cross wires. Analogue studies by W. R. Simmons at ANL show that the effect of the cross wires on surface temperature is equal to that produced by the peripheral film drop variation, when assuming that the cross wire blankets, or in effect insulates, a 30 degree arc. Since these factors are not additive, the design is not handicapped by the effect of wire contact. On this basis, spacing between wires in each grid is not critical; thus broad tolerances are permissible.

Special Geometries

A. *Twisted Ribbon Fuel Elements*

Twisted ribbons may be defined as narrow plates, or flattened cylinders, that have been twisted about the longitudinal axis to form a helical or spiral surface as shown in Fig. 5.[4]

When twisted ribbon fuel elements are used, the surface to volume ratio is higher than that obtained with plates because the coolant flows over the entire surface. Also the ribbon is narrow and the area on the sides becomes an appreciable percentage of the heat transfer surface. This edge area is probably quite effective as turbulent flow will occur in this region even when the edge is rounded. Thus the ratio is $2/t + 2/w$, where t is the thickness and w is the width of the ribbon.

Such elements when held at the ends are completely

[4] Proposed by C. R. Breden, Argonne National Laboratory.

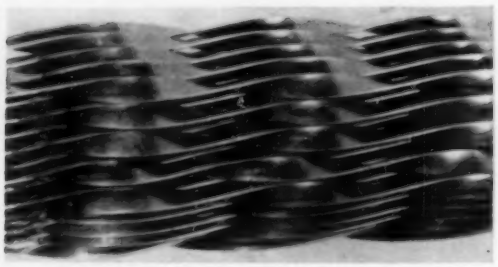

Fig. 5—Twisted ribbon type fuel elements

self-supporting along their length; thus the elements may be long and slender. The contact between adjacent elements is at a point where helical edges cross at an angle to each other. The fuel element to coolant ratio may be varied by varying the width to thickness ratio of the ribbon.

Some turbulence is produced by the helical form of the ribbons; however, the heat transfer rates are probably closer to the pure parallel flow case than to the cross flow over tube banks. Unfortunately, the form of the ribbons produces cross currents of coolant that meet in the area between elements. Thus the maximum turbulence does not occur on the surface of the element where it would improve the heat transfer rate. Tests must be run to determine the performance of such elements; and until that time, heat transfer calculations must be based on speculation. Pressure drop tests run at Argonne National Laboratory indicate a relatively small increase in pressure drop over that for parallel plates.

The mixing of the coolant along the flow path assures the localizing of hot spot effects. The contact points are probably negligible hot spots, since excellent coolant flow exists all around the point of contact. In addition, there is an edge effect where a greater heat transfer area per unit of fuel volume occurs.

B. *Fuel Matrix with Coolant Passages*

Many possibilities exist, based upon varying fabrication techniques, for a "Swiss Cheese" design, that is, a block of fuel with coolant passages through the block (Fig. 6). The surface to volume ratio for such a design is dependent upon the number and size of the coolant passages and is not readily reduced to a form for comparison with previous fuel element geometries. For cylindrical coolant passages,

$$R = \frac{N\pi dl}{1 - [N(\pi d^2/4)/l]}$$

where

N = Number of coolant passages
d = Diameter of coolant passages
l = Length of coolant passages

Such a design has the same limitations as any disconnected parallel flow channel design; however, it may be desirable for certain applications.

C. *Pebbles and Berl Saddles*

Pebbles, or spheres, have the highest surface to volume ratio of all geometries. The ratio is $6/d$ where d is the diameter of the sphere. If mass production techniques can be applied, a pebble bed will be a very desirable

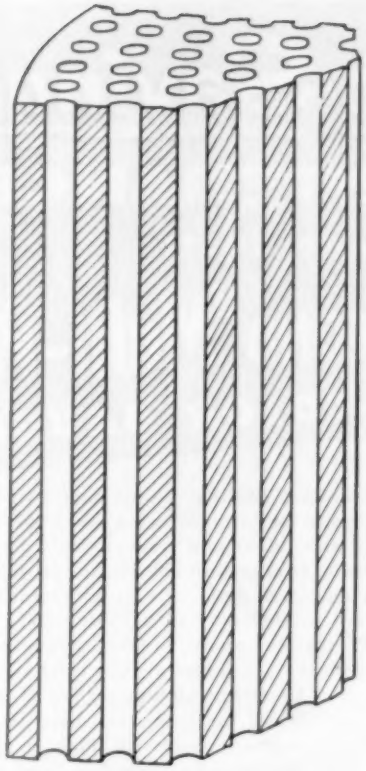

Fig. 6—Fuel matrix with integral coolant passages

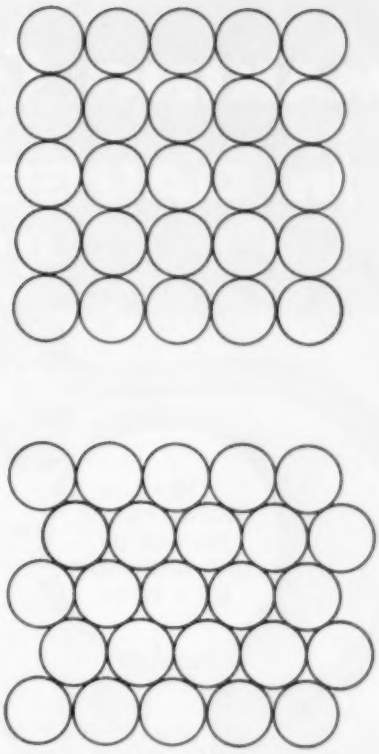

Fig. 7—Packing arrangements obtained with spherical fuel elements

design. The turbulent flow through the bed gives the same advantages as the crossed wire grid; however, the problem of fuel element support, that is, the containment of the pebbles within the core, is different. The pebbles are self-supporting, and thus require only a containment structure that will permit adequate coolant flow into and out of the core.

A problem arises from the non-uniform packing that results as illustrated in Fig. 7. The spheres can pack either in the square or triangular pattern show. This will result in very undesirable variations in the density of spheres, and therefore of fuel throughout the core.

Another form has been suggested by Mr. L. W. Fromm, formerly of ORNL, as shown in Fig. 8; this is

Fig. 8—Berl saddle type fuel elements

the berl saddle. It has the advantage of very uniform packing, and has given the same density within less than 1 per cent by simple methods of filling a cylindrical volume.

This form is produced very easily in a single operation by pressing a flat disk in a suitable die.

D. *Molecule*

The molecule of fuel in a liquid fuel reactor appears to be the ideal fuel element. The maximum surface to volume ratio and the ultimate in heat transfer area per unit of fuel is obtained. The form is simple, easily "fabricated," and presents no mechanical support or stability problems. Structural material consists of the non-uranium atoms of the molecule, and there is no *fuel element* corrosion problem.

This appears to be the only fuel element to consider. However, this design, like so many other "ideal designs," trades one set of problems for another. Thus the interest in solid fuel elements continues.

Conclusion

The fuel element geometries discussed in this paper have been based on inherently simple forms, such as plates, cylinders and spheres. These basic elements may be formed into various configurations and assembled to form a simple or complex core assembly. The selection of the elements and the complexity of the assembly must be based upon the balance between cost and performance demanded by the specific application under consideration.

It has been shown that simplicity of fuel element form and of core assembly can be attained. It may also be seen that the complication of design for high performance reactor cores need only be that resulting from the increased number of elements required, as they are reduced in thickness in order to obtain large heat transfer areas.

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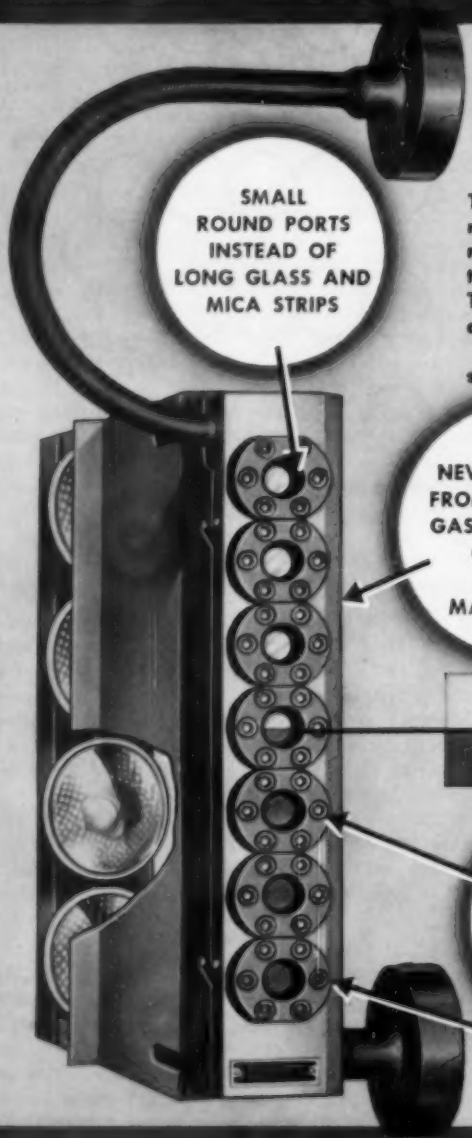
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Economic Comparison of Steam-Turbine Vs. Motor-Driven Boiler Feed Pumps*

By A. G. MELLOR, R. C. MUIR, J. F. O'MARA and J. F. RANSOM

General Electric Company

The purpose of this AIEE paper is to present an economic comparison between steam turbine and motor drives for boiler feed pumps as an aid in determining the area of economical application of each of these types of drives.

BEFORE the development of the extraction turbine, many steam-electric generating station auxiliaries were driven by steam turbines with the exhaust of these turbines being used for feedwater heating. The general adoption of feedwater heating by extraction from the main turbine led to a re-evaluation of auxiliary drives. Improvements in the reliability of motors and auxiliary power supply systems made the use of all electric drives for power station auxiliaries attractive. For the size of generating units and steam pressures commonly being used, the all-electric auxiliary system generally showed a saving in first cost over turbine drives. The result has been the practically universal use of all electric drives in modern generating stations.

Recently there has been considerable interest shown in utilizing steam turbines to drive boiler feed pumps. This interest is due to several factors among which are the following:

1. The trend to larger generating units using higher steam pressures which has resulted in much larger boiler feed pump power requirements.
2. The development of boiler feed pumps operating at speeds above 3600 rpm. These high speed pumps are more economical, particularly for the higher pressure units.
3. The difficulty of designing an auxiliary power system to handle the very large amounts of pumping power required by large generating units operating at high steam pressures.

Basis of Economic Comparisons

In comparing the relative economics of motor driven and turbine driven boiler feed pumps, three major factors must be considered:

1. Initial investment
2. Evaluation of incremental station output
3. Net station heat rates.

A. Initial Investment

1. When turbine driven boiler feed pumps are used, a considerable saving can be achieved in the auxiliary power supply system. Figs. 1 and 2 show these savings including auxiliary transformers, switchgear, cable, bus run and grounding equipment.

2. When turbine driven pumps are used it is often possible to reduce the auxiliary power system voltage from 4160 volts to 2400 volts. The savings in the price of 2300 volt motors over 4000 volt motors are shown in Fig. 3.

3. The cost of motor driven variable speed pump and pump drives is shown in Fig. 4.

4. Fig. 5 shows the prices of turbines and turbine driven pumps. These prices are based on the type of turbines described later.

5. The estimated costs of turbine piping and piping installation are shown in Fig. 6.

B. Evaluation of Incremental Station Output

When turbine driven boiler feed pumps are used, normal auxiliary power requirements are reduced and the net station output can be increased by providing additional boiler, condenser and main step-up transformer capacity.

1. Fig. 7 shows estimated average total plant investment cost and boiler plant cost. These costs were used to determine the value of the incremental station output as explained under "Method of Analysis."

2. Fig. 8 shows the incremental net station output available when turbine driven pumps are used.

3. The cost of extra condenser capacity was assumed to be $10 per kilowatt of output and the incremental cost of additional capacity in the main power transformer was assumed to be $1.70 per kilowatt of increased output.

C. Net Station Heat Rates

Preliminary studies have shown that at full load the use of turbine driven boiler feed pumps will result in a slight gain in net station heat rate. At lower loads motor driven pumps may give a better heat rate. Considering the expected load cycle of most generating units it was assumed that the station heat rate for the two types of drives could be taken as a stand-off when evaluated over the life of the unit. In certain cases where

* Presented at the Winter General Meeting of the American Institute of Electrical Engineers, New York, N. Y., Jan. 30-Feb. 3, 1956.

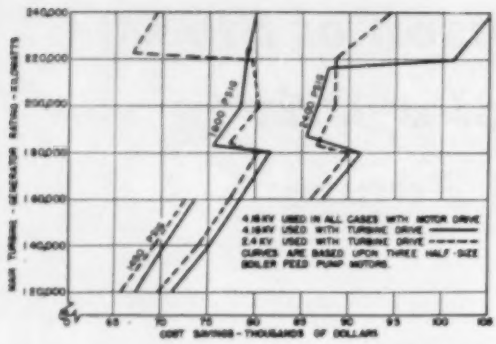
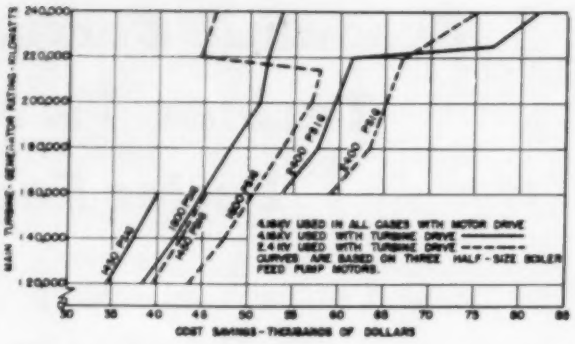

4.16 KV USED IN ALL CASES WITH MOTOR DRIVE
4.16 KV USED WITH TURBINE DRIVE
2.4 KV USED WITH TURBINE DRIVE
CURVES ARE BASED UPON THREE HALF-SIZE BOILER FEED PUMP MOTORS.
COST SAVINGS - THOUSANDS OF DOLLARS

Fig. 1—Price savings of auxiliary power supply systems using turbine instead of motor driven boiler feed pumps. Two auxiliary transformers used for motor drive. Single auxiliary transformers used for turbine drive


4.16 KV USED IN ALL CASES WITH MOTOR DRIVE
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2.4 KV USED WITH TURBINE DRIVE
CURVES ARE BASED ON THREE HALF-SIZE BOILER FEED PUMP MOTORS.
COST SAVINGS - THOUSANDS OF DOLLARS

Fig. 2—Price savings of auxiliary power supply systems using turbine instead of motor driven boiler feed pumps. Two auxiliary transformers used for both motor and turbine drive

unusual loading cycles are encountered, the effect of station heat rate should be more accurately evaluated.

Method of Analysis

A. Initial Investment

In determining the difference in investment cost between motor and turbine drives for the various arrangements studied, only those components of the station that change in size or rating were considered. The savings in cost of the components that can be eliminated or reduced in size when turbine drives were used were totaled. From this total the net saving (if any) that could be achieved was determined by subtracting the cost of the turbines, required piping and piping installation. These net savings are shown in the lower part of Figs. 14, 15 and 16. It should be noted that in Fig. 14 the initial investment for turbine drives is less than for motor drives. However, in Figs. 15 and 16 the initial investment for motor drives is less than for turbine drives.

The following investment cost comparisons have been made:

1. Fig. 14 shows the comparison between using one full size turbine drive against two half size motor drives.
2. Fig. 15 shows the comparison between using two half size turbine drives against two half size motor drives.
3. Fig. 16 shows the comparison between using two full size turbine drives against three half size motor drives.

For each of the above comparisons, 3600 rpm motors and variable speed pumps were compared with high speed (5500–9000 rpm) turbines and pumps. Also presented are data on the price of 1800 rpm motors, variable speed drives and gears driving high speed pumps.

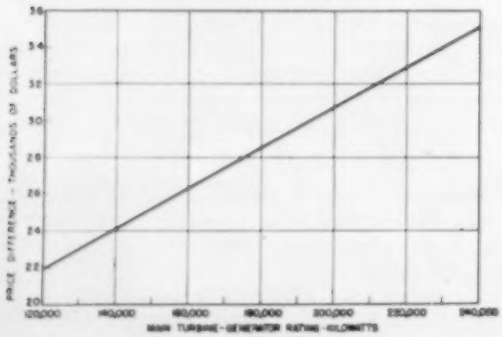


Fig. 3—Total price difference between 4000 volt motors and 2300 volt motors excluding boiler feed pump motors

Fig. 9 gives the total auxiliary power requirements at various steam pressures for systems using either motor or turbine driven boiler feed pumps. It can be seen that the power requirements of the boiler feed pump motors make up a large percentage of the total requirements of the auxiliary power system, being about 42 per cent at 2400 psi. Thus when turbine driven boiler feed pumps are used, the size and cost of the auxiliary power system are reduced considerably.

Three basic arrangements of auxiliary power systems were studied as shown in Fig. 10. Arrangement No. 1 is a split bus using two auxiliary power transformers. This arrangement was used in all cases where the boiler feed pumps were motor driven. Arrangements No. 2 and 3 are single auxiliary power transformer arrangements and are feasible when turbine drive is used.

For all size units under consideration auxiliary power system voltage of 4.16 kv was used when the boiler feed pumps were motor driven. Therefore, all costs were based upon a 4.16-kv auxiliary power system voltage when motor drive was used. However, by using steam turbine drives for the boiler feed pumps, either a 2.4-kv or a 4.16-kv auxiliary power system voltage was suitable. Therefore, the investment costs using both voltages have been considered when using turbine drive. Generally speaking, the 2.4-kv system is lower in cost due to the lower cost motors, motor feeder switchgear cubicles, start-up transformer and elimination of neutral grounding resistors.

The following assumptions were used in determining the ratings of the various components of the auxiliary power system.

1. The auxiliary power system power factor was 0.85.
2. Circuit breakers were type AM-2.4/4.16—150/250.
3. For Arrangement No. 1, the auxiliary power transformer ratings were each one-half of the actual auxiliary power requirements.
4. For Arrangements No. 2 and 3, the auxiliary power transformer ratings were equal to the actual auxiliary power requirements as determined from Fig. 9.
5. Auxiliary power transformers were type OA-T.

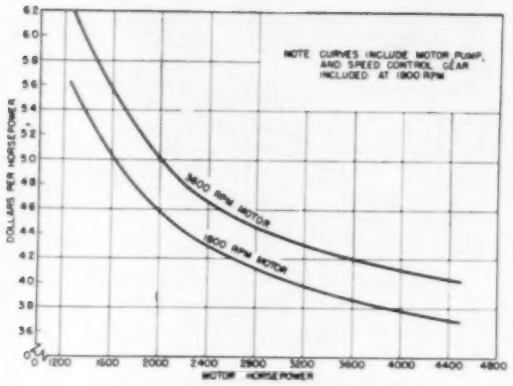

NOTE CURVES INCLUDE MOTOR PUMP, AND SPEED CONTROL GEAR INCLUDED AT 1800 RPM
3600 RPM MOTOR
1800 RPM MOTOR
DOLLARS PER HORSEPOWER
MOTOR HORSEPOWER

Fig. 4—Motor and pump price

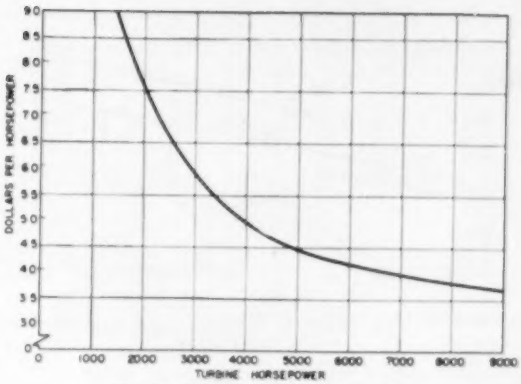


Fig. 5—Turbine and pump price

6. Start-up transformers were type OA-FA.

7. Start-up transformer fan-cooled rating was equal to the actual auxiliary power requirements of one unit.

8. For calculating momentary fault currents, 100 per cent motor load at either 2.4 kv or 4.16 kv was assumed.

9. The allowable voltage drop was 15 per cent when starting the largest motor.

10. When using turbine driven boiler feed pumps, the horsepower rating of the largest motor considered for calculating voltage drop was one-half the size of the boiler feed pump requirements.

11. The high voltage bus was at 138 kv.

12. The main exciter was shaft connected to the generator.

Figs. 1 and 2 show the results of these comparisons and give the dollar savings in the auxiliary power system by going from motor driven to turbine driven boiler feed pumps, as a function of maximum turbine-generator rating for any size unit from 120,000 kw to 240,000 kw, and at steam pressures ranging from 1450 psig to 2400 psig. The results shown in Figs. 1 and 2 are based on three half-size boiler feed pump motors. If two boiler feed pump motors are to be used, $12,500 should be subtracted from the cost savings shown on Figs. 1 and 2, to take into account the extra equipment required for the third motor. These curves also include provisions for a small auxiliary pump motor, and the necessary control equipment which is required to obtain pressure in the boiler during start-up, when the boiler feed pump is turbine driven.

Fig. 11 gives the calculated required motor and turbine capacities for driving the boiler feed pumps. The curves are based upon a maximum steam flow of 110% of turbine rating and include an additional flow margin of 10% for pump wear and transient conditions. 3600-rpm motors are assumed. If 1800-rpm motors are to be considered, the horsepower requirements of the motor should be increased by 2% to account for the gear efficiency. The curves are based on one full capacity drive. Thus if two or three half capacity drives are to be used, the horsepower rating as determined from the curve should be divided by two. The horsepower requirements of a turbine are less than that of a motor for a given size unit because the speed control for the pump is inherent in the turbine and hence no additional loss factor need be considered. If a throttling valve is used with motor drive, the required motor horsepower will also be greater than the turbine horsepower to provide the throttling losses. However, use of a throttling valve does not provide the equivalent variable speed performance obtainable from a turbine drive.

When the required motor size is determined from Fig. 11, the price can be found from Fig. 4. The curves include the complete price of a motor, pump and method of speed control. The 1800-rpm motor curve includes the price of a gear for driving a high speed (5500–9000 rpm) pump. Prices given are for one pumping unit. If two or three motors are used, the appropriate multiplier is necessary.

In going from a 4.16-kv system to a 2.4-kv system, a considerable saving can be realized in the cost of the remaining auxiliary motors. Fig. 3 gives the approximate dollar savings that can be reasonably expected.

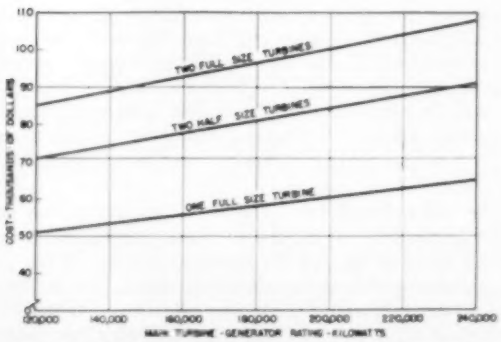

TWO FULL SIZE TURBINES
TWO HALF SIZE TURBINES
ONE FULL SIZE TURBINE
COST - THOUSANDS OF DOLLARS
MAIN TURBINE - GENERATOR RATING - KILOWATTS

Fig. 6—Additional station piping and piping costs

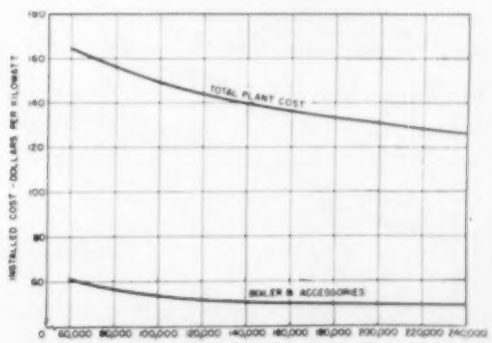


Fig. 7—Total plant and boiler and accessory cost

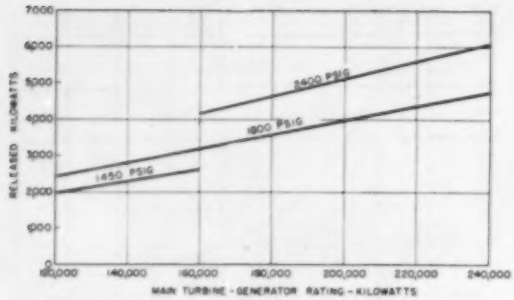


Fig. 8—Full load kilowatts released using turbine driven boiler feed pumps

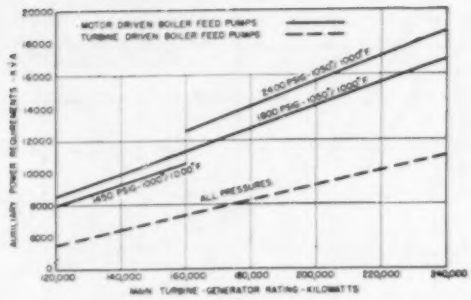

MOTOR DRIVEN BOILER FEED PUMPS
TURBINE DRIVEN BOILER FEED PUMPS
AUXILIARY POWER REQUIREMENTS - KVA
2400 PSIG 050° 1000°F
1800 PSIG 1050° 1000°F
450 PSIG 1000° 1000°F
ALL PRESSURES
MAIN TURBINE-GENERATOR RATING-KILOWATTS

Fig. 9—Auxiliary power requirements

The sum of the dollars obtained from Fig. 1 or 2, plus Figs. 3 and 4, is the total dollar investment price savings in the auxiliary power system in going from motor to turbine driven boiler feed pumps.

Fig. 5 gives the steam turbine and pump prices. The curve is for a 450 psig, 750 F unit with arrangement for admitting steam at full boiler pressure and temperature on start up and light load operation and extraction for feed water heating. The following accessories have been included: turning gear, turning gear pump, auxiliary oil pump, air motor speed control, tachometer and other required accessories.

Fig. 6 gives approximate piping and piping installation costs for the complete turbine installation. The curves are based upon the piping arrangement of Fig. 17. The prices of all valves are included.

The curves in the lower portions of Figs. 14, 15 and 16 give the difference in total plant investment costs when comparing motor driven and steam turbine driven boiler feed pumps. The curves are based on an auxiliary power system voltage of 2.4 kv when using turbine drive, and are also based on 3600-rpm motors and pumps. Using a 4.16-kv auxiliary power system voltage when using turbine drive is more expensive in all cases studied, and therefore would make the motor drive appear more favorable.

Using 1800-rpm motors and high speed pumps instead of 3600-rpm motors and pumps results in a lower initial investment. Fig. 4 shows that for a given horsepower rating the dollars per horsepower for the high speed pump drive unit is less than for the 3600-rpm drive unit.

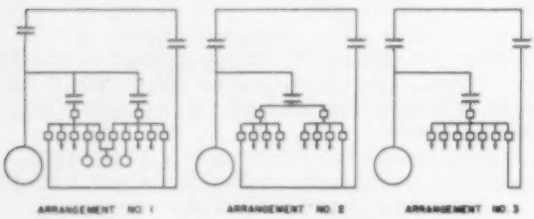


Fig. 10—Auxiliary power system arrangements

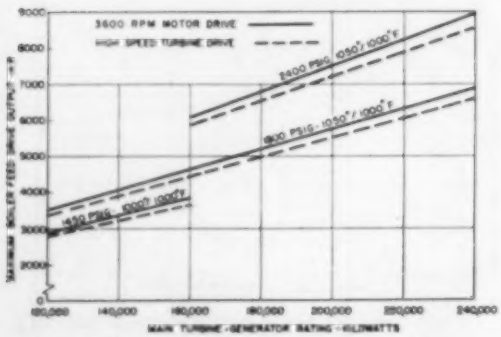


Fig. 11—Total boiler feed pump capacity

B. Evaluation of Incremental Kilowatts

In comparing turbine driven against motor driven boiler feed pumps for a given size turbine-generator, more kilowatts are available at the high voltage bus when using turbine drives. This is due to the capacity released from the auxiliary bus by eliminating the large size motors. However, in order to actually obtain these kilowatts, the size of the boiler, its associated accessories, the condenser and the main power transformer must be increased. A method is presented here for evaluating these additional kilowatts.

Fig. 7 shows costs of complete power stations and costs of only the boiler plant portion of the power station. These curves are based on coal-fired plants and are average installed costs based on actual plants in all parts of the country. The actual cost of a given plant will differ from that shown on the curves depending upon the physical location of the plant. However, the shapes of the curves should apply regardless of location.

From the curve shown in Fig. 7 a curve of total dollar investment for various size units was determined. By taking the slope of this curve, a curve of incremental station cost was obtained.

To obtain increased net output of the station when turbine driven boiler feed pumps are used, it is necessary to increase the boiler capacity and also to provide extra capacity in the condenser and main step-up transformer.

The incremental cost of extra boiler capacity was obtained from the curve of boiler costs shown in Fig. 7. To this incremental boiler cost was added $10 per incremental kilowatt for extra condenser capacity and $1.70 per incremental kilowatt for extra transformer capacity.

The net value of the incremental station output was taken as the difference between the incremental value of station investment and the incremental cost of the station components that must be increased to obtain the increased net output. Fig. 12 is a plot of the value of incremental kilowatts in dollars per kilowatt for various sizes of units.

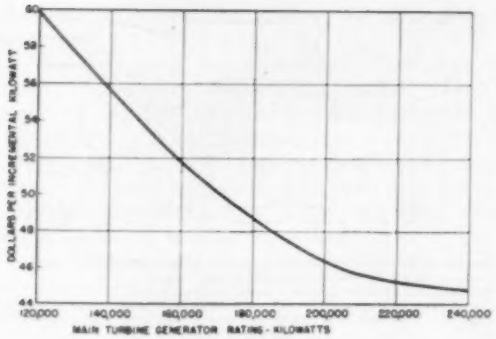


Fig. 12—Evaluation of incremental kw additional capacity

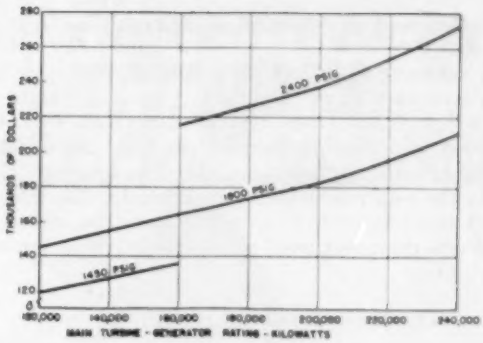


Fig. 13—Total incremental kilowatt dollar evaluations

Fig. 13 showing the total incremental kilowatt dollar evaluation was obtained by multiplying the values shown on Fig. 12 by the additional station output shown on Fig. 8. Fig. 8 shows the actual kilowatt capacity released under normal full load operation of the turbine-generator.

It is realized that the evaluation of incremental station output is a controversial subject and that the method presented here is only one approach to the problem. Many utilities use higher values than shown here and at least one utility uses a figure of $100 per incremental kilowatt.

The upper portion of Figs. 14 through 16 are composite curves showing the total dollar comparison including incremental kilowatts as a result of using turbine driven boiler feed pumps. These curves are obtained by combining the lower portion of Figs. 14 through 16, and Fig. 13.

Arrangement of Boiler Feed Pump Turbines

Studies have been made of many arrangements of boiler feed pump turbines in the plant cycle. Based upon these studies, it must be concluded no one arrangement is categorically better than the other. Turbines can be designed to operate on steam extracted from the cold reheat line or any extraction from the main unit. Exhaust can be to the condenser or to a feedwater heater and with or without extraction for other feedwater heaters. Some generalized rules should be kept in mind, however, when studying the application of boiler feed pump turbines. Selection of cycle arrangement must be made compatible with flexibility of operation at light load and under abnormal conditions such as load trip out, heaters out of service, etc.

Turbine efficiency varies with volume flow and for this reason the boiler feed pump turbine efficiency will be poorer than that of the main unit. This difference may be kept to reasonable limits by selecting a boiler feed pump turbine for low inlet steam conditions.

In the sizes generally considered, the initial cost of the turbine will be lowest for initial steam pressures of about 400 psig. Cost will also vary with initial steam temperature. These factors suggest operation from the cold reheat line. Operation from the cold reheat line has the apparent effect of by-passing the reheater. This will not, however, affect the cycle adversely if all the steam

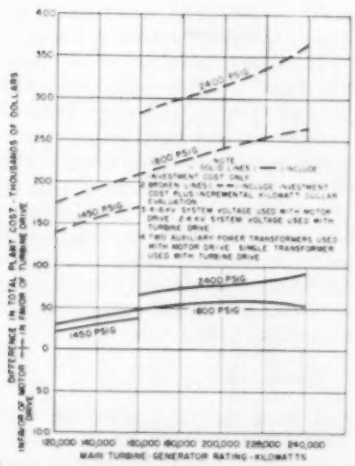


Fig. 14—Economic comparison of steam turbine vs. motor driven boiler feed pumps. One full size high speed turbine vs. two half size 3600-rpm motors

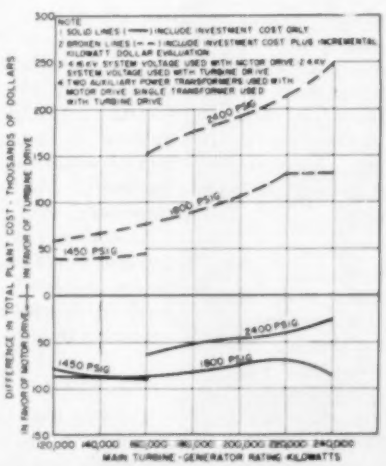


Fig. 15—Economic comparison of steam turbine vs. motor driven boiler feed pumps. Two half size high speed turbines vs. two half size 3600-rpm motors

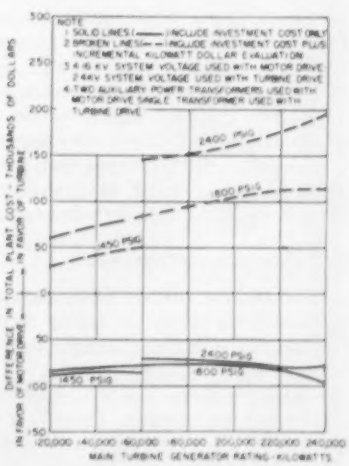


Fig. 16—Economic comparison of steam turbine vs. motor driven boiler feed pumps. Two full size high speed turbines vs. three half size 3600-rpm motors

thus bypassed is exhausted or extracted to feedwater heaters.

Condensing turbines offer a possibility of cycle heat rate economies by virtue of the fact some large units may have high exhaust losses. A condensing boiler feed pump drive would, in effect increase the total annulus area. These benefits may be completely offset if steam is taken from the cold reheat line, thus bypassing the reheater. Inlet steam taken from an extraction of the reheat turbine or a cross-over point will result in a more favorable heat rate.

A. Operation of Turbine Drives

The details of control and operation are subject to considerable variations depending upon the preferences of an individual. For purposes of this study, one arrangement has been selected to describe in detail.

Fig. 17 shows a cycle arrangement in which steam is normally taken from the cold reheat line and exhausted to the deaerating heater and at reduced load to the cross-over of the main unit. The boiler feed pump turbine has two extractions to high pressure closed heaters. For start-up and light load operation, a separate admission is provided for steam taken directly from the high pressure line.

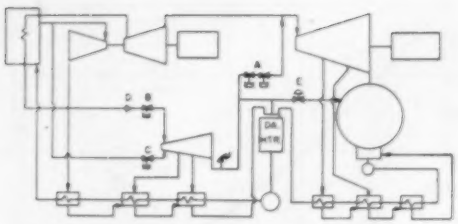
The ability of the deaerating heater to absorb the heat in the steam from the exhaust of the boiler feed pump turbine is a function of feedwater temperature and feedwater flow to the heater. As load on the main unit is reduced, flow of feedwater to the deaerating heater is also reduced but boiler feed pump power, and hence exhaust steam flow from the boiler feed pump turbine, are not reduced so rapidly. It is for this reason that a tie to the main unit cross-over is made. Exhaust steam in excess of that which can be absorbed in the deaerating heater flows into the main unit. At very light loads, during start-up or in case of load rejection, no steam should be admitted to the main unit. For these conditions, the admission valves to the main unit are tripped closed and a dump valve to the condenser is opened.

With proper consideration to the heat cycle arrangement, it should be possible to operate without the need for supplemental high pressure steam admission to below half load on the main unit. At some point, however, it will be necessary to admit high pressure steam. Part of the load range will be served by both sources of steam. As load on the main unit is further reduced, the pressure of the cold reheat steam will diminish to the point that it is lower than the first stage shell pressure. A non-return valve therefore must be provided to prevent a back flow of steam to the cold reheat admission.

B. Control of Turbine

The turbine driven boiler feed pump may be speed governed in terms of boiler feedwater requirements. Conventional boiler controls, operating through an air motor, position a pilot valve in the hydraulically relayed governing system.

For boiler feed pump drives, a special turbine has been developed for which more accessories are available than is normal for this size of turbine. This is desirable since in most instances there will be requirements for remote starting, quick starting and perhaps automatic starting. The list of accessories available includes turning gear, remote indicating gages, tachometers, control valve



(A) ADMISSION-EXTRACTION STOP VALVES(DOUBLE PROTECTION) TO CROSS-OVER OF MAIN TURBINE
(B) STOP VALVE - COLD REHEAT ADMISSION TO BOILER FEED DRIVE TURBINE
(C) STOP VALVE - HIGH PRESSURE ADMISSION TO BOILER FEED DRIVE TURBINE
(D) NON RETURN TO PREVENT BACK FLOW WHEN STARTING PUMP DRIVE TURBINE ON HIGH PRESSURE STEAM
(E) DUMP VALVE TO CONDENSER - OPENS ON HIGH DEAERATING HEATER PRESSURE - OPEN DURING START - UP

Fig. 17—Valve and piping arrangement

position indicators and remotely operable valves for the seal system.

C. Starting

Some form of motor driven boiler feed pump capacity must of necessity be employed to start the plant. In the case of conventional boilers for pressures up to say 2400 psig, motor driven pumps capable of only a few hundred pounds per square inch and flow equivalent of no load flow on the main unit may be employed. With steam admission provided from the main header as well as the cold reheat line, it is possible to start the turbine driven boiler feed pump with as little as 200 to 300 psig boiler steam pressure. From this point, there will be sufficient margin of steam power over pump power required to bring the boiler up to full pressure. This includes sufficient flow to start the main unit on reduced pressure as well.

When high speed pumps are used it may be necessary to provide small motor driven booster pumps from the deaerating heater to the suction of the boiler feeders. The booster pumps in this case must be capable of full flow requirements. In either case, the motor driven feed pumps may be of small horsepower ratings and therefore, no great burden on the auxiliary power system.

It is, of course, possible to provide a motor driven feed pump, capable of full pressure and part flow. This may, in fact, be the desirable thing to do in the case of once-through boilers and boilers for supercritical pressures. Here there has been a requirement that full pressure and some minimum flow be established prior to lighting off the fires. Since, in this case, motor driven pumps could satisfy the part load requirements, the feature of admission from the main header could be eliminated with, of course, a reduction in turbine cost. This does not, however, provide a complete solution to the problem of large motor drives and expensive auxiliary power systems. More ideas will certainly be coming forth in this area, as more experience is gained in the operation of large supercritical boilers.

Conclusions

1. For the range of main generator unit sizes and steam pressures considered in this study, turbine drives for boiler feed pumps cannot be justified on investment cost alone unless a single, full sized turbine drive with no spares is considered.

2. For the three types of comparisons made, turbine drives were justified in all cases when the increased net

output of the station was evaluated at the level used in this paper.

3. It does not appear to be economical to install more than two turbine drives per generating unit since the installed cost of two full sized turbine drives is about a stand off with three half sized turbine drives.

4. As generator unit size and steam pressure increase, it appears that turbine drives become slightly more favorable from an investment cost point of view. At sizes and steam pressures beyond those considered in this study, the practical limit of conventional 4160 volt auxiliary power systems will be reached if motor driven boiler feed pumps are used. At this point there will be a sharp increase in the cost of motor drives and auxiliary equipment.

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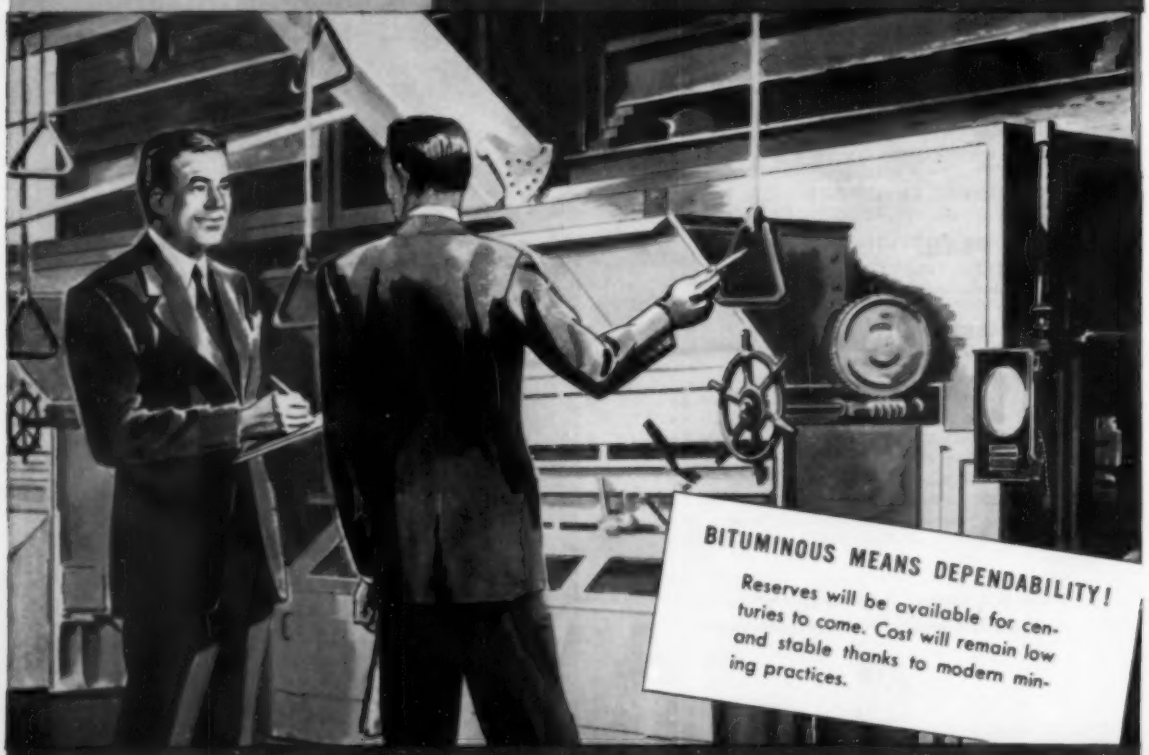

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X-ray Analysis as a Guide to Chemical Cleaning

By

A. W. COULTER, C. M. MADDIN, and R. B. ROSENE

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IN today's speeded-up industry, maintaining operating equipment at peak efficiency is of prime importance. As a result, maintenance engineers have relied more and more on chemical cleaning to provide maximum operating capacity with a minimum of shut-down time. Experience has shown that scale deposits, if allowed to accumulate in boilers and heat exchangers, reduce efficiency, and as a result, increase unit operating costs. Periodic removal of such deposits frequently pays for itself due to increased economy of operation.

The chemical solvent method of deposit removal conforms to the modern trend toward increasing efficiency. It provides the advantages of reduced shut-down time, more thorough removal from otherwise inaccessible areas, elimination of costly dismantling, and maximum protection to the equipment being cleaned.

Determining Type of Scale

Chemical scale removal methods have been used successfully on many different types of industrial equipment containing many kinds of deposits. The physical and chemical composition of the scale frequently differs markedly with differences in mineral content of the liquids from which it is deposited, as well as various conditions of operating temperature. Due to the wide variety of scales which may be encountered under different operating conditions it is of prime importance that the equipment to be cleaned undergo thorough preliminary inspection. At this time, representative samples of the deposits involved should be taken for laboratory examination. A general rule is that such samples should be selected from an area where deposition is the heaviest, or the highest operating temperatures are encountered. Analysis of such samples to determine their chemical constituents and structure, serves as a basis for the selection of the proper solvent for the cleaning operation.

Value of X-ray Analysis

X-ray analysis of scale samples has proved a valuable guide in identifying scale constituents. The analysis of deposit samples should identify not only the individual elements therein, but should also reveal the compounds or chemical structure of the scale. This latter information is essential in planning the treatment, and determining which solvents and application techniques will result in most rapid efficient removal of the deposit.

For example, the identification of iron and oxygen would be insufficient, due to the various possible forms in which iron oxide might be present. The utilization of X-ray analysis reveals the presence of magnetite, hematite, goethite, hydrogoethite, lepidocrocite or some amorphous form of hydrated iron oxide, such as limonite; the specific form or forms encountered determining choice of chemical solvents and treating conditions. Thus, identification of the crystalline structure of the scale deposit by X-ray analysis provides a rapid and efficient tool in conducting chemical cleaning operations.

Analysis of deposit samples should identify not only the individual elements therein but should also reveal the compounds or chemical structure of the scale. X-ray analysis will do this.

Frequently, the occasion arises where it is difficult to obtain a sizable sample of deposit, or time limitations do not permit a complete chemical analysis of the scale. In such cases, the use of X-ray diffraction techniques is indispensable for identifying the chemical constituents of the deposit, permitting the service engineer to select the optimum solvent and cleaning procedure for the scale removal treatment.

Naturally, similarity of equipment and operating conditions in different industries frequently makes possible the planning of cleaning operations on the basis of past experience without individual analysis of every deposit. In such cases, however, these recommendations are based on previous cleaning jobs on similar units, which in turn were based on X-ray scale analysis.

The technique of chemical analysis by X-ray diffraction was originally introduced by Hull (7) and later systematized by Hanawalt, Rinn and Frevel (6) who laid the basis for the system which has been adopted by the American Society for Testing Materials and is now in international use.

Scale Analysis Techniques

X-ray diffraction, using the powder camera technique, has been utilized for over 10 years, for the identification of scale forming deposits. The use of this technique for scale analysis has been reported by Fitzgerald (5). Important among the more recent instrumental developments is the improved Debye-Scherrer Powder Camera (8). However, in this era of automation a more direct recording device, a Geiger counter X-ray spectrometer, has gained in popularity as a useful X-ray diffraction tool. This accessory permits a conventional X-ray analysis to be performed with greater speed and accuracy than generally found with the powder camera technique, as well as eliminating photographic variables such as film shrinkage.

The apparatus utilizes a Geiger counter tube which traverses a 180 degree semicircular path over which X-

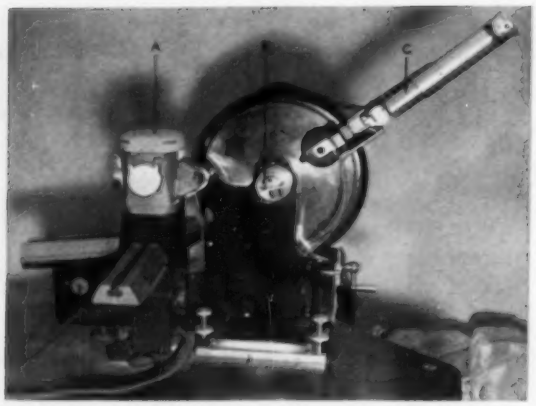

Fig. 2—Geiger counter goniometer: A, X-Ray tube housing; B, sample; C, Geiger Counter tube.

Fig. 1—Geiger counter X-ray spectrometer: Basic X-ray unit shown at left with wide range goniometer. Electronic circuit panel at right with electronic strip chart recorder

rays, diffracted at characteristic angles by the specimen, are detected and their intensities recorded on a strip chart recorder. A photograph of the complete apparatus may be seen in Fig. 1, showing the basic diffraction unit on which the Geiger counter goniometer is mounted. To the right is the electronic circuit panel with the strip chart recorder. The geometric relationship that exists between the sample or specimen, the X-ray beam, and the Geiger counter is illustrated in Fig. 2. It may be seen from this that the Geiger counter merely replaces the sensitized film, such as used with a powder camera, as a detector.

Embodied in the strip chart recorder is a device which records the angular travel of the Geiger tube at intervals of one-half degree. This angular measurement corresponds to 2 Θ, where Θ is an angular term in the Bragg equation, expressing the fundamentals of X-ray diffraction. Substitution of the angular measurement into the Bragg equation, $n\lambda = 2d \sin \Theta$, allows the computation of "d," the interplaner spacing. This distance between atomic planes is characteristic of the crystal. Because of this, one crystalline compound can be distinguished from another by X-ray diffraction. The geometry of the crystal determines the number of different interplaner spacings to be found for a given compound. Although limitations of this paper do not permit a more detailed treatment of the principles of X-ray diffraction, readers interested in pursuing the subject at greater length are referred to a series of papers by Firth (2, 3, 4)* or the monograph by Clark (1)

Selection of Proper X-Ray Tube

When irradiated with light of a characteristic wave length, some compounds will emit a secondary radiation, fluorescence. When this occurs during X-ray diffraction, the resultant X-ray pattern is diffuse and difficult to interpret. Consequently, an X-ray tube should be selected which will avoid fluorescence. Knowledge of which compounds would be expected to fluoresce when irradiated by light from commercially available X-ray tubes should permit selection of the proper tube. This information is tabulated in Table I, which also indicates the appropriate filter material to insure a monochromatic X-ray beam. The copper target tube is commonly used for general X-ray diffraction tests. However, because most industrial deposits contain iron compounds that result in fluorescence, the copper target tube usually is not used for scale analysis. For most samples, the iron target tube is satisfactory, due to the general absence of chromium compounds in deposits. Whenever the presence of chromium is noted in a deposit, however, a molybdenum target tube is used.

TABLE I
CHARACTERISTICS OF X-RAY TUBES WITH DIFFERENT TARGETS

Target	Wave length of Emitted Radiation, Angstroms	Filter	Element Causing Fluorescence
Iron	1.9360	Manganese	Chromium
Molybdenum	0.7093	Zirconium	Yttrium
Copper	1.5405	Nickel	Cobalt, Iron

The radiation from the molybdenum target tube produces fluorescence only with yttrium compounds, and for this reason it might seem expedient to use it for all work. However, this is not desirable because the dispersion (separation of diffracted X-radiation) is low compared to that obtained from an iron target tube, due to the relatively short wave length radiation produced by the molybdenum target tube (see Table I).

Another factor which must be considered is the relative error incurred in the determination of the "d"

* Numbers in parentheses refer to Bibliography at end of the article.

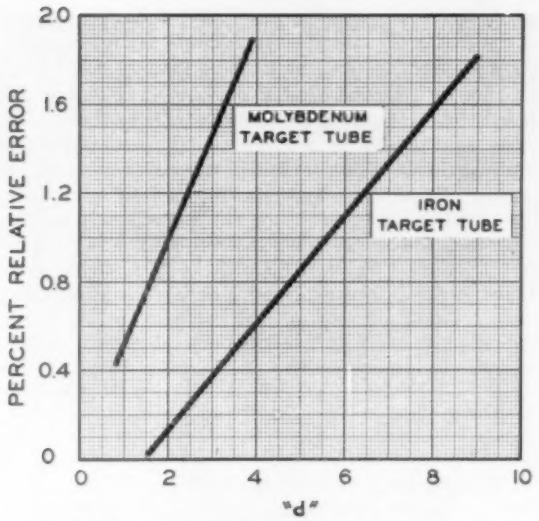

Fig. 3—Relative error in determination of "d" with iron and molybdenum target tubes for a constant error of ± 0.2 degrees in determination of 2 Θ

spacings. This can be determined from the reproducibility of the 2 Θ values on the strip chart at positions of maxima in the pattern. Experimentally, this has been found to be approximately ± 0.2 degrees when the Geiger counter traverses its path at a speed of 2 degrees/minute. For a given "d" spacing then, a 0.2 degree error in determining 2 Θ will result in a larger variation from the true "d" spacing when molybdenum target radiation is used than when iron target radiation is used. This is illustrated graphically in Fig. 3 and shows the greater degree of relative error that must be expected if a molybdenum target tube is used, rather than an iron one.

Procedure For Scale Deposit Identification

The first and perhaps most important step in the identification of a deposit is that of sample preparation. A representative portion (about one gram) of the deposit is ground until it will pass through a 200-mesh sieve. This requires special care, as incomplete grinding and sieving may effect a separation of the more refractory components, and permit them to escape detection.

The powdered deposit must then be packed into a sample holder, and mounted on the Geiger Counter goniometer (see Fig. 2). In cases where the sample size is too small for the goniometer, the powder camera may be used, for it requires only a few milligrams of sample. When the sample is in place the X-ray beam is directed on it, while the Geiger counter goniometer detects the diffracted X-rays. Both the angle of diffraction and the intensity of the diffracted radiation are recorded by the strip chart recorder.

Typical X-ray diffraction patterns are shown in Fig. 4. These were obtained from samples containing various amounts of iron (111) oxide and metallic copper, as indicated. Variation in peak height with concentration is apparent also, the iron (111) oxide peaks being indicated by the latter A and the copper peaks by B. This permits a quantitative determination of the constituents present as well as their qualitative identification. The

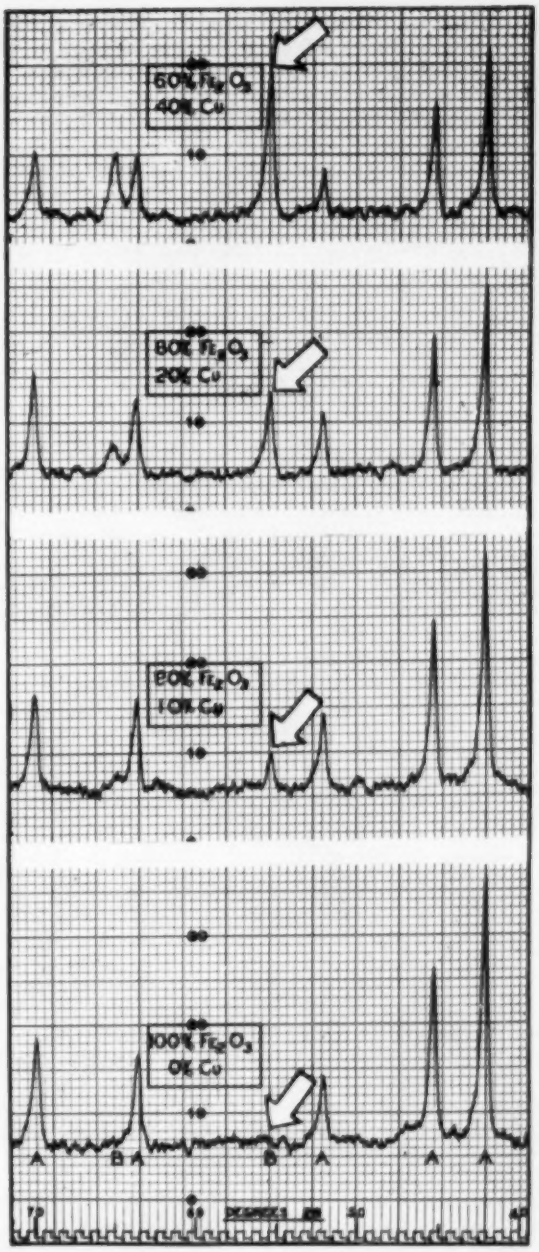

Fig. 4—X-Ray spectrometer patterns: A, peaks corresponding to Fe_2O_3; B, peaks corresponding to Cu. Arrow shows increasing intensity of copper peak with increasing concentration

accuracy of the determination is about 10 per cent of the amount present. In cases where higher accuracy is sought, the goniometer may be set manually on a given peak and the intensity of the radiation recorded on the electronic circuit panel, eliminating the scanning speed of the goniometer as a variable.

Composition of Typical Deposits

Many different chemical compounds have been found in scale deposits. Some of the more typical compounds

found in these deposits are listed in Table II. The mineralogical names are given because of their broad usage rather than the less common chemical names. Deposits peculiar to specific industries are encountered less frequently but are often characterized by X-ray analysis also. Ferric gluconate ($Fe(CH_2OH)(CHOH)_4COO)_2$) as a process side deposit in the sugar industry affords an excellent example.

TABLE II
TYPICAL DEPOSITS IDENTIFIED BY X-RAY DIFFRACTION

Name	Formula
Acmite	$Na_2O \cdot Fe_2O_3 \cdot 4SiO_2$
Analcite	$Na_2O \cdot Al_2O_3 \cdot 4SiO_2 \cdot 2H_2O$
Pectolite	$Na_2O \cdot 4CaO \cdot 6SiO_2 \cdot H_2O$
Hydroxyapatite	$Ca_{10}(OH)_2(PO_4)_6$
Serpentine	$3MgO \cdot 2SiO_2 \cdot H_2O$
Hematite	Fe_2O_3
Magnetite	Fe_3O_4
Copper	Cu
Alpha Quartz	SiO_2

Evaluation of Scale Removal Efficiency

Some insight into the efficiency of the scale removal treatment can be obtained by an analysis of the drained solvent and comparing it with the X-ray analysis of the deposit. Solvent analysis is made spectrochemically (8) for the different elements in the solvent. Often the presence of a particular element provides a basis for calculating the quantity of a given scale component dissolved. This can be seen from Table II if we consider a mixed deposit containing acmite, analcite, and pectolite because each has at least one element which is not common to the other two materials. Hence, an analysis of the solvent for iron, aluminum, and calcium would be indicative of the relative amounts of acmite, analcite, and pectolite dissolved respectively.

Correlations of this type have been found very useful in predicting the extent of success achieved in the cleaning operation. The following case histories are presented to illustrate the use of such correlations, their value and limitations.

Case 1

X-ray analysis of the deposit indicated a mixture of hematite (Fe_2O_3), hydroxyapatite ($Ca_{10}(OH)_2(PO_4)_6$) and serpentine ($3MgO \cdot 2SiO_2 \cdot H_2O$). Spectrochemical analysis of the used solvent for iron, calcium, and magnesium provided a means of correlating the quantity of each material removed. When the results of the solvent analysis were reported in terms of the original compounds found by X-ray analysis, the relative amounts of each component were about the same by both methods. This indicated that the solvent had acted on all components of the deposit and could be expected to remove it. Visual inspection of the unit followed by an observation of its operating efficiency provided the ultimate basis for judging the treatment. While the importance of the solvent analysis should not be underestimated it must be remembered that the results are relative and cannot be expressed in terms of a percentage of the total deposit removed because this latter quantity is rarely, if ever, known.

Case 2

Pectolite ($Na_2O \cdot 4CaO \cdot 6SiO_2 \cdot H_2O$), analcite ($Na_2O \cdot Al_2O_3 \cdot 4SiO_2 \cdot 2H_2O$) and alpha quartz ($SiO_2$) were found in the deposit by X-ray analysis. Solvent analysis for calcium and aluminum showed that pectolite and analcite had been removed in approximately the same proportions as indicated present by the X-ray analysis. Inasmuch as silicon was present in all three components the quantity of alpha quartz removed could not be determined. Small amounts of dissolved iron (probably from Fe_2O_4) and phosphate (probably from $Ca_{10}(OH)_2(PO_4)_6$) were also found in the solvent. Compounds containing these constituents were not found by X-ray analysis of the deposit. Such lack of correlation between solvent analysis and X-ray analysis of the deposit is relatively common. This is generally due to a sample which is not entirely representative of the scale to be removed, or to failure of the X-ray analysis to detect the presence of minor components. In general, components whose concentration is less than five percent of the total are not expected to be recognized by X-ray analysis. The lower limit of detection is even higher for some compounds (6).

Case 3

The deposit was found to be about three-fourths magnetite (Fe_3O_4) and one-fourth copper (Cu). The solvent selected was of such a nature that only the magnetite would be dissolved. Consequently analysis of the used solvent showed iron as the major element present, and a trace of copper. It is not infrequent that occasions arise in which one solvent will not satisfactorily remove every component of a scale deposit. This is not objectionable in cases in which the undissolved components are disintegrated well enough to be flushed out of the unit. In the case of copper as an undissolved scale component, it is often necessary to make a second treatment with a special non-acid copper solvent.

The cases cited provide a cross section of the many types of deposits encountered. They illustrate situations in which X-ray analysis has indicated both soluble and insoluble materials for a given solvent. For this reason the use of X-ray analysis has proved to be an important aid in planning a chemical cleaning procedure.

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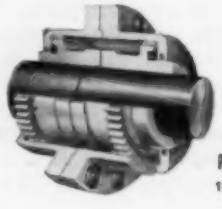

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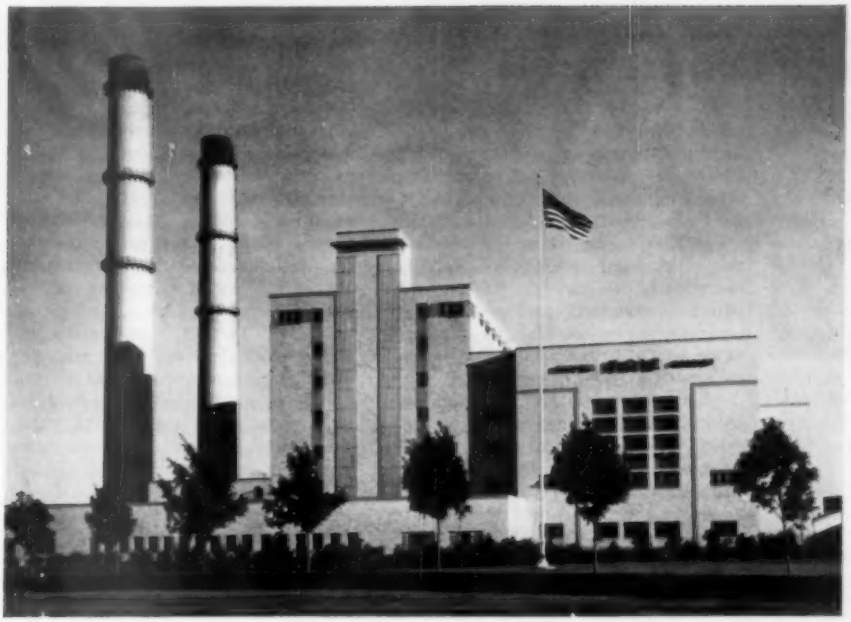

Exterior view of Russell Station showing how landscaping harmonizes with station architecture

Russell Station Wins "Plant America" Award

On January 5, at the Eastern Nurserymen's convention at the Hotel Roosevelt, New York City, Rochester Gas & Electric Corp. was honored with the presentation of the National "Plant America" Award of the American Association of Nurserymen. This was in recognition of the attractive landscaping of Russell Station located along the shores of Lake Ontario in a suburban residential district a few miles from Rochester. The company was cited "for achievement in industrial landscaping and beautification contributing to employee and civic pride in our American heritage."

L. J. Cooley, Superintendent of Electric and Steam Generation, shown receiving award from Vernon Marshall, (right), president of American Association of Nurserymen

Aerial view of Station and surrounding countryside. Note Lake Ontario on left and residential area in foreground

Highlights of Nuclear Engineering and Science Congress—II

IF nuclear power is to become competitive with conventional power, steps must be taken to keep operating costs at a minimum. One area that promises substantial cost reductions relates to the reprocessing of spent nuclear fuels. In an atomic power plant this is a counterpart to the collection and disposal of ash required in a coal-burning central station. At the meeting a series of six papers was presented on methods of reprocessing nuclear fuels, including consideration of the economics of the several methods.

A. F. Voight of the Ames Laboratory of Iowa State College described a method for removing fission products and plutonium from irradiated uranium by melting and extracting with another molten metal which is immiscible with uranium. Silver, cerium and lanthanum have been used as the extracting metal. Plutonium is effectively removed by silver and to a lesser degree by the rare earth metals. The alkali and alkaline earths metals are removed by volatilization in all instances. The rare earths are removed by extraction as is zirconium. Ruthenium and molybdenum are only fractionally removed. The method shows promise as a way of regenerating spent and radiation damaged fuel using remote processing and refabrication.

High temperature or pyroprocessing methods show great possibilities of achieving large economies in the cost of processing metallic and fused salt types of spent fuel according to **J. R. Folz, F. D. Rosen,** and **W. J. Gardner** of North American Aviation, Inc. The advantages of these methods arise from the facts that (a) the fuel is processed in a highly concentrated form and no dissolution and dilution is necessary, (b) the small volume of the process stream plus the small volume of reagents results in large savings in plant size and in operation costs, (c) generally, the waste streams are very resistant to radiation damage and so concentrated storage is possible at an appreciable saving in cost, (d) the process streams are also resistant to radiation damage so very short cooled fuels can be handled with a significant savings in fuel inventory charges.

Pyrometallurgical processes generally produce a considerable amount of fumes and particulate matter, uranium and thorium systems being no exception. Spent fuel processing therefore requires that considerable effort be expended in controlling these fumes and particles because of the radioactivity associated with the spent fuel. Also these metals and many of their compounds rapidly react with ordinary air at the elevated temperatures employed. Therefore atmosphere control may require more space and equipment than is required for the processing itself.

The most persistent problems associated with high temperature processing are in the materials of construction field. Not only are liquid metals and fused salts extremely corrosive but the specific ones used in nuclear reactors, e.g., uranium and thorium, are also very heavy and have high melting points. The high density results in fairly high unit loadings on containers and at the same time the high temperature drastically reduces the strength of most materials. Remotely operated equipment has been developed for some of these processes to melt, contact, separate phases, take samples, and dispose of waste products on the kilogram scale. As more experience is gained in pyroprocessing spent nuclear fuels the various operational methods are expected to improve.

Results of an industrial participation contract between Vitro Corporation of America and AEC were set forth by **Sidney M. Stoller** of Vitro. As part of this program, a conceptual design study and cost estimate of a small chemical processing plant was carried out.

Chemical processing is still a government monopoly and there is no private company offering commercial reprocessing services to the nuclear power field. Further, the government experience is mostly in the area of large plants to handle the vast capacity required for the defense program. It was for the purpose of analyzing the reasons for this apparent vacuum and to assay the opportunities for the organization to participate commercially in this field that Vitro undertook a study program.

Periodic reprocessing of reactor fuels is required (1) to prevent loss of reactivity of the reactor due to fission product poisoning; (2) to prevent or repair irradiation damage to the fuel elements; and (3) to recover unburned fuel and new fuel produced from fertile materials.

Problems of chemically processing irradiated material include all of those normally associated with operation of conventional complex chemical plants, plus unique problems resulting from the unusual properties of the material being processed. The conventional problems also are magnified in these plants to an unusual degree; for example, to achieve the high degree of decontamination required for direct refabrication, one must separate fission products which are initially present in the feed in concentrations of parts per million, by a factor of 10^7. A similar situation exists with respect to the recovery of the valuable fissionable materials produced, where recovery of 98 per cent or better are desirable to effect fuel cycle economy; and where, again the initial concentration of these materials may be measured in parts per million.

The special problems are (1) those associated with the effects of radioactivity, i.e., decomposition of process chemicals and plant materials, such as lubricants, gaskets, electrical insulation; and (2) those emanating from the absolute requirements to prevent the inadvertent accumulation of a critical mass of fissionable material under any conceivable condition of operation.

Another special problem is waste disposal, which is almost the controlling consideration in the economics of chemical separations.

The frequency of reprocessing is dependent upon the type and design of the reactor. In a homogeneous reactor reprocessing might be done continuously by bleeding off a side stream from the main circulating fuel system. This side stream can be chemically processed to remove the fission products as required to prevent loss of reactivity, with recycling of unburned or new fissionable material. The decontamination factor, i.e., efficiency of the fission product removal, can conceivably be much lower with this type of reactor, since there is no fabrication required to put the fuel back into usable form.

On the other hand, in a reactor using a complex fabricated fuel element, reprocessing can be visualized as chemical or mechanical decladding. This must be followed by some type of dissolution and then by separation and disposal of the cladding and alloying components to waste. The metal stream would then be fed to solvent extraction for separation and decontamination of the recoverable metal products to allow direct refabrication. This is followed by reduction of the aqueous metal salt solution to a metal form and, finally, refabrication of the fuel elements.

In the case of the liquid-metal-fuel

reactor it is believed that roughly 45 per cent by weight of the fission products can be continuously removed from the fuel by salt-extraction with alkali and alkaline-earth fused salt mixtures, according to **O. E. Dwyer** of Brookhaven National Laboratory. These fission products contain the highly "poisonous" rare earths.

For the low fission-product concentrations desired in the LMFR, the rate of fuel processing is necessarily high when one thinks in terms of the pounds of fuel which must be handled per day; but for a high-density liquid fuel such as U-Bi, where continuous operation can be used, actual flow rates are estimated to be less than a gallon per minute for reactors having heat rates as high as 1000 mw.

At Brookhaven National Laboratory, according to **Robert J. Teitel** of that group, data were collected to show that fractional precipitation processes appear feasible for treatment of fission waste products in a liquid-metal-fuel reactor. The steps in the process would include (1) adjustment of concentration of alloy; (2) thermal treatment to attain equilibrium distribution of radiation products; (3) lower the temperature and separate the U intermetallic compounds by filtration, centrifuging or settling techniques; (4) purify the liquid phase; and (5) recombine residue of step 3 with purified filtrate of step 4 and return the dispersion to the reactor.

This technique has far reaching possibilities in that it could be applied to other systems such as U dispersions for plutonium breeder blankets, plutonium fuels and Th breeder blankets. The latter application is being considered actively at Brookhaven. Experimental values have been obtained and indicate that favorable processes for the removal of U from a Th-Bi dispersion are possible.

K. K. Kennedy and **D. G. Reid** of Phillips Petroleum Company presented a paper based on experience with a radio-chemical processing plant associated with the materials testing reactor. The Idaho Chemicals Processing Plant, located at the National Reactor Testing Station near Idaho Falls, has three objectives: (1) to recover the unused enriched uranium from spent fuel elements from the AEC's National Reactor Testing Station experimental reactors and other AEC sites, (2) to prove under production commitments at high levels of fission product activity, that plants can use commercially available conventional materials and not require the tremendously expensive, specially designed tools required for remote maintenance, and (3) provide processing cost data for various types of prototype fuels which can be used, with confidence, in economic studies of proposed large scale recovery operations.

The chemical process consists simply of dissolution of the uranium-aluminum fuel in nitric acid, solution clarification by filtration, feed adjustment by volume reduction, neutralization of excess acid and three cycles of liquid extraction using methyl isobutyl ketone as the extractant in columns packed with stainless-steel raschig rings.

Power Reactor Safety

"Interpretation of the Purpose, Scope, and Operation of the Reactor Safeguards Committee" was the title of a paper by **C. Rogers McCullough** of Monsanto Chemical Co. This committee reviews the hazards associated with all reactors and significant changes in them and makes recommendations to the general manager of the Atomic Energy Commission. This evaluation is based upon a Hazards Summary Report which describes the reactor design, supervision, containment, and location, plus an analysis of creditable accidents and the provisions to prevent them. A Reactor

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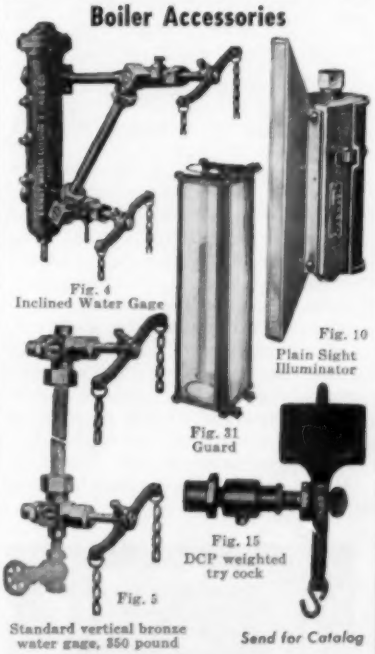

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Fig. 10 Plain Sight Illuminator

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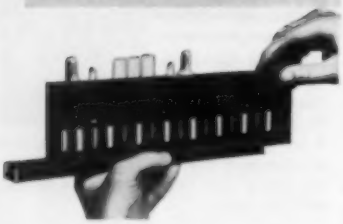

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Hazard Evaluation Staff is being formed to take over the technical part of the work. The Advisory Committee on Reactor Safeguards will evolve standards as rapidly as possible. For the first few nuclear power plants it is believed that a cooperative effort with the Advisory Committee and the Reactor Hazard Evaluation Staff will result in the quickest practical instruction, and at the same time help to evolve a set of standards for the future.

It is worth pointing out that this is the first time that at the start of a major industrial development an attempt is being made to predict the possible accidents and to take steps to prevent them as a matter of government policy. In the past, regulations have been written after the accidents. Attempting to write regulations before the accidents has its difficulties. It might be argued that the method of experience where a small industry with a few people involved is permitted to grow and make its mistakes is better. However, the atomic energy industry is not small. It has already grown to huge proportions and the proposed power reactors are very large expensive machines.

New Books

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The Dilworth Story

By Franklin M. Reck

McGraw-Hill, 105 pages, $3

Biographies of engineering pioneers often make for exciting reading, and this is no exception. Richard Dilworth served as chief engineer of Electro-Motive Corp., now a division of General Motors Corp., from 1926 to 1950. Over this quarter of a century, he is credited with the development of the diesel locomotive to its present place of prominence on the railroads of the world.

The career of Mr. Dilworth was marked by the determined accomplishments from a humble beginning typical of the American tradition. Lacking formal engineering education, Mr. Dilworth nevertheless learned technology the practical way in the manufacturing shop and on the railroad. His unshakable confidence in the internal-combustion engine, and particularly the diesel, was ultimately rewarded by the sale of the first passenger diesel locomotives which went into service in 1935. From that point on, the adoption of the diesel progressed at an accelerating rate.

This book should be of interest to those young persons contemplating engineering as a career, for it illustrates the part personal traits play over and beyond technical knowledge in the life of an engineer of considerable accomplishment. The author has told about Mr. Dilworth in a conversational, informal way that makes the book a delight to read.

Industrial Furnaces, Vol. II, Third Edition

By W. Trinks

John Wiley & Sons, 358 pages, $10

In the third edition of this authoritative work on industrial furnaces, the author incorporates major advances taking place since 1941. Included in the new information are the following items:

- More complete information on fuels
- Relation between grindability, fineness and cost
- New tunnel burner
- New burners for luminous flames and raw producer gas
- Principles of induction heating
- Temperature control in high-speed heating
- Examples of furnaces with protective atmospheres
- Centrifugally cast furnace rollers
- Rotating furnace
- Conveyors for salt baths
- Cost data on recuperators

A completely new chapter on safety measures for furnace operators has been added. The author, who is now a partner of Associated Engineers, Pittsburgh, Penna., is widely known as a teacher of mechanical engineering at Carnegie Institute of Technology, where he was department head for 37 years. For those interested in the design, construction and operation of industrial furnaces, this is probably the most complete work available.

Chemical Engineering Materials

By Frank Rumford

Chemical Publishing Co., 382 pages $7.50

Selection of materials involves the application of a number of engineering specialties. This book, based on Bri-

tish practice, is of interest to both chemical and mechanical engineers who are called upon to determine suitable materials for chemical plants. Many of the same considerations apply to steam power plants, particularly these criteria for an ideal material:

- Unattacked by the chemical reagents used (or by quality of feedwater makeup supplied)
- Without influence on the chemical process (or the generation and condensation of steam and flow of feedwater)
- Mechanically reliable and easily fabricated
- Essentially economic in cost

The author opens with an explanation of the mechanism of corrosion and the common methods of testing materials. He then proceeds to take up specific materials, including many metals, protective coatings, cements, refractories, glass, wood, plastics and rubber. In each instance, corrosion-resistance data are given and typical applications in the chemical industry are outlined. Three useful appendices are included, one providing a ration chart of the resistance of common metals to specific chemicals, another setting forth mechanical properties of materials, and a third giving a correlation of British Standards and ASTM Specifications.

Modern Physics for the Engineer

Edited by Louis N. Ridenour

McGraw-Hill, 499 pages, $7.50

Modern Physics

By John C. Slater

McGraw-Hill, 322 pages, $5.50

These two books, though similar in title and subject matter, are very different in approach. Because of this difference, they both have a place in the library of the intellectually curious engineer who desires to keep abreast of important developments in the many categories of so-called modern physics.

"Modern Physics for the Engineer" is an outgrowth of an extension lecture course offered at the University of California, Los Angeles, in 1952–53. The book is divided into three parts, of which the section entitled "The Laws of Nature" represents physics as it is concerned with matter, radiation and the laws of their interaction. "Man's Physical Environment" is a section which deals with the application of physical laws to the study of the universe, the earth and the air. A third part, "Information and Its Communication," is concerned with the field of modern elec-

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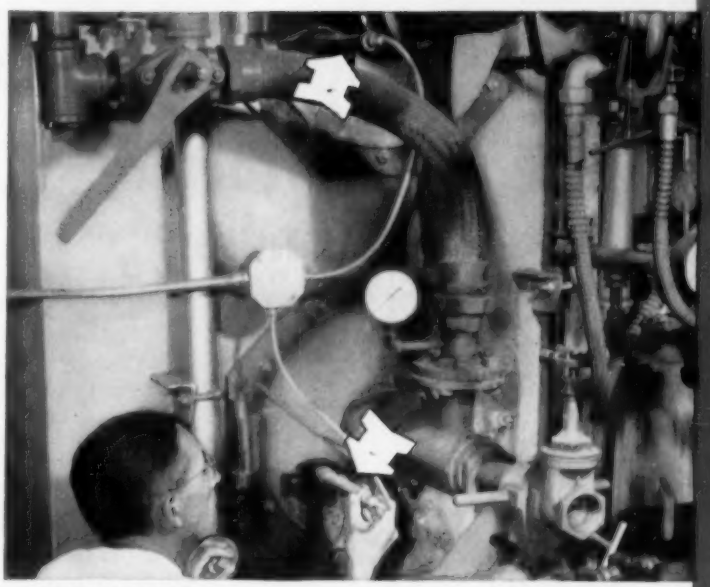

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tronics, including semi-conductors and computing machines.

Throughout the book the editor has attempted to maintain a comprehension level between the monograph of the specialist and popularized approach to physical topics. The book assumes a general familiarity with the methods and results of physical science, but no specialized knowledge of the subjects treated. Much of the material is of a semi-descriptive nature, but it is believed that many engineers will find the authoritative accounts of such subjects as astrophysics, geophysics, underwater phenomena, thunderstorms and lightning strokes of considerable interest.

In contrast to the lecture-survey approach of the Ridenour work, Prof. John C. Slater of Massachusetts Institute of Technology has defined modern physics in a more limited fashion and has concentrated on the development of ideas that marked the transition from so-called classical physics to modern physics as it is now known. Prof. Slater points out that modern physics has taken the structure of the atom, which was largely a field for speculation in 1900, and has brought it to the point where it forms a precise, quantitative, mathematical branch of physics.

Furthermore, according to Prof. Slater, "the forward-looking engineer must accustom himself to following the day-to-day progress of physics, keeping his eye constantly open for practical applications. The best way to train himself for this is to follow the exciting developments of the past fifty years, so that he can learn how physicists think, what problems they work on, and can be alert when new discoveries are made."

Topics covered in the book include the atom in 19th century physics, electron theory and relativity, quantum theory, various 20th century concepts of the atom, X-rays and crystal structure, atomic and molecular spectra, wave mechanics and nuclear physics. As was mentioned earlier, the emphasis is on linking the ideas underlying modern developments, and therefore the approach is more historical and philosophical than mathematical. The busy engineer who can find the time to spend perhaps eight or ten hours on this book will find that his time will be richly rewarded in terms of increased comprehension of the really exciting intellectual achievements that underlie modern physics.

With the rapid pace of modern technology, engineers cannot afford to ignore developments of the basic natural science of physics. These two books represent exceptionally able efforts to interpret modern physics in a manner that will appeal to all engineers who realize that education must continue throughout their professional careers.

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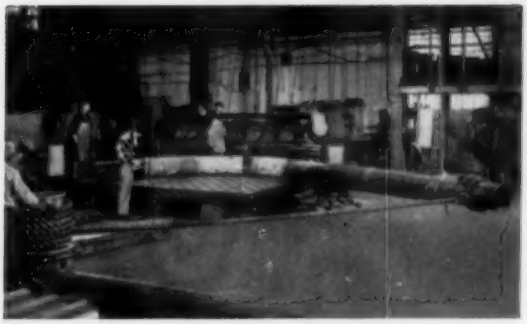

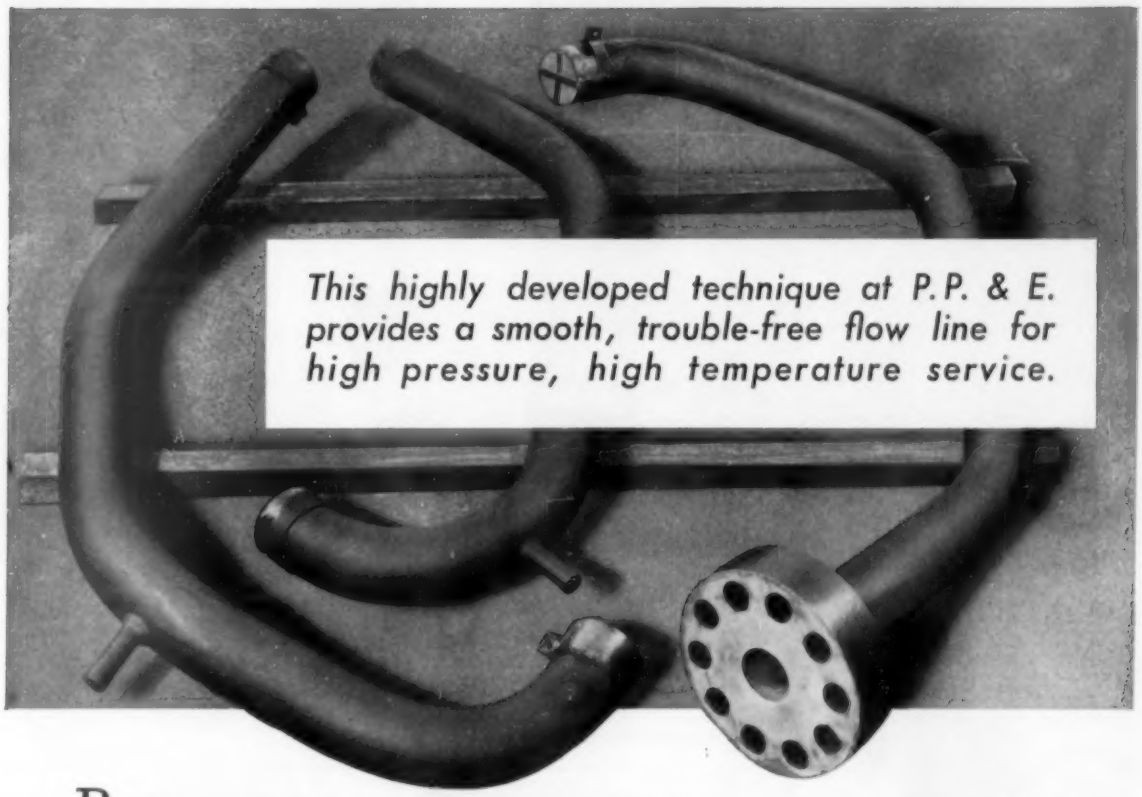

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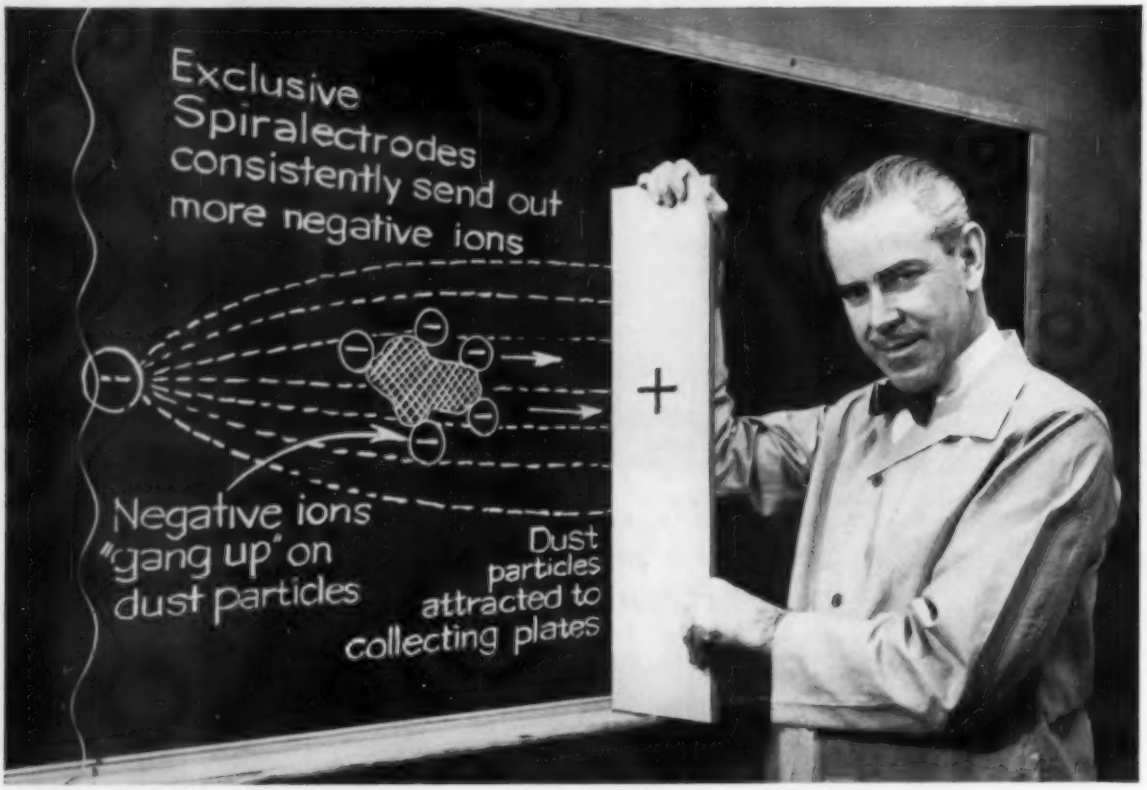
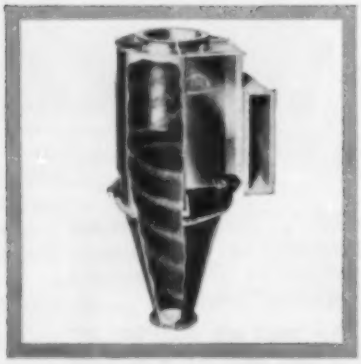
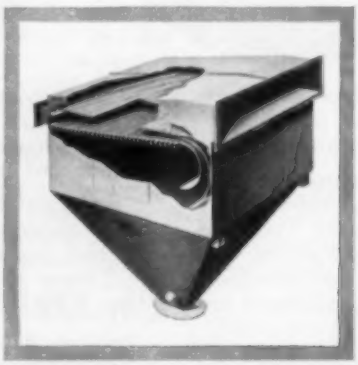
How a Buell Collection System "gangs-up" on dust to meet the toughest air pollution codes





Buell Cyclones also deliver extra collection efficiency to "gang-up" on dust: Exclusive Shave-off design harnesses double-eddy current and puts it to work.

With positive gas flow control for peak efficiency . . . plus continuous cycle rapping to eliminate puffing . . . Buell's "SF" Electric Precipitator really "gangs-up" on dust (even dust with high resistivity) to permit full production even under the most rigid anti-air-pollution codes.



Buell's Low Resistance Fly Ash Collector combines high efficiency to meet present day strictness, with low draft loss for natural or mechanical draft installations.

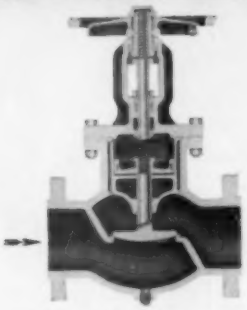
FOR THE COMPLETE STORY
Write:
Buell Engineering Company
Dept. 70-B, 70 Pine Street
New York 5, New York

buell®

MECHANICAL ELECTRICAL

Experts at delivering Extra Efficiency in **DUST COLLECTION SYSTEMS**

FOSTER IN THE STEAM PLANT



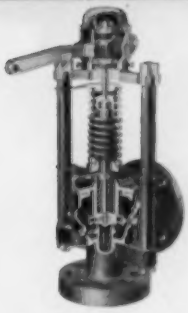
Type 2S

NON-RETURN VALVES

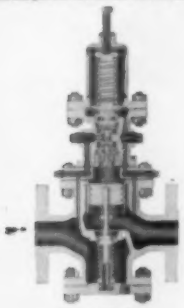
Foster Automatic Non-Return Stop and Check Valves are made for pressures up to 900 P.S.I. and 900°F. Globe, angle or elbow pattern body design; 2½" to 12"

SAFETY VALVES

Foster Super-Jet Safety Valves for steam pressures up to 3000 P.S.I. and 1100°F_2 tight seating, have high relief capacity, pop accurately, are adjustable for minimum blow-down and can be completely serviced *in the line* Flanged or welding ends.



Type 38-SV



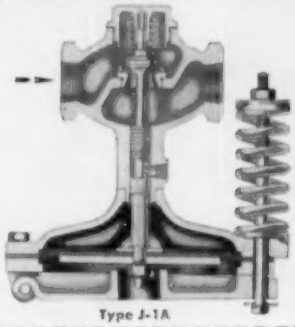
Type 50-G2S

PRESSURE REDUCING VALVES

Foster 50-G2 Regulators for high pressure steam are internal pilot operated for extreme accuracy approaching instrument type control. They handle a very wide reduction and often eliminate the need for a secondary stage valve. Self-contained or arranged for remote control.

PRESSURE REDUCING VALVES

Foster J-1A Regulators for low pressure are spring loaded, diaphragm actuated. They are designed primarily for steam heating systems, and are especially suitable for intermittent or dead-end service where the required reduced pressure is relatively close to the available inlet pressure.



Type J-1A

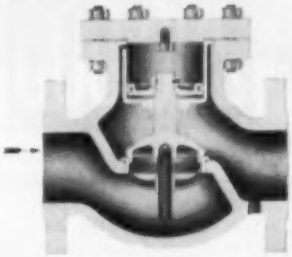
Gentile (*Gen-til'ly) Flow Tube

FLOW TUBES

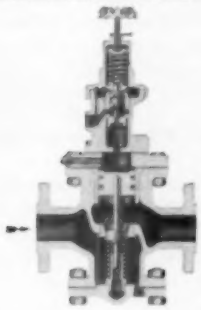
The Gentile Flow Tube is an impact type head meter or differential producer for extremely accurate measurement of fluid flow. It requires no straight runs unless installed near throttling valves or regulators. Each tube furnished with individual head capacity curve.

CHECK VALVES

For positive, noiseless operation, Foster Cushion Check Valves are available in suitable materials and construction for either high or low pressure lines. Bodies are streamlined for minimum pressure drop.



Type CKH



RELIEF VALVES

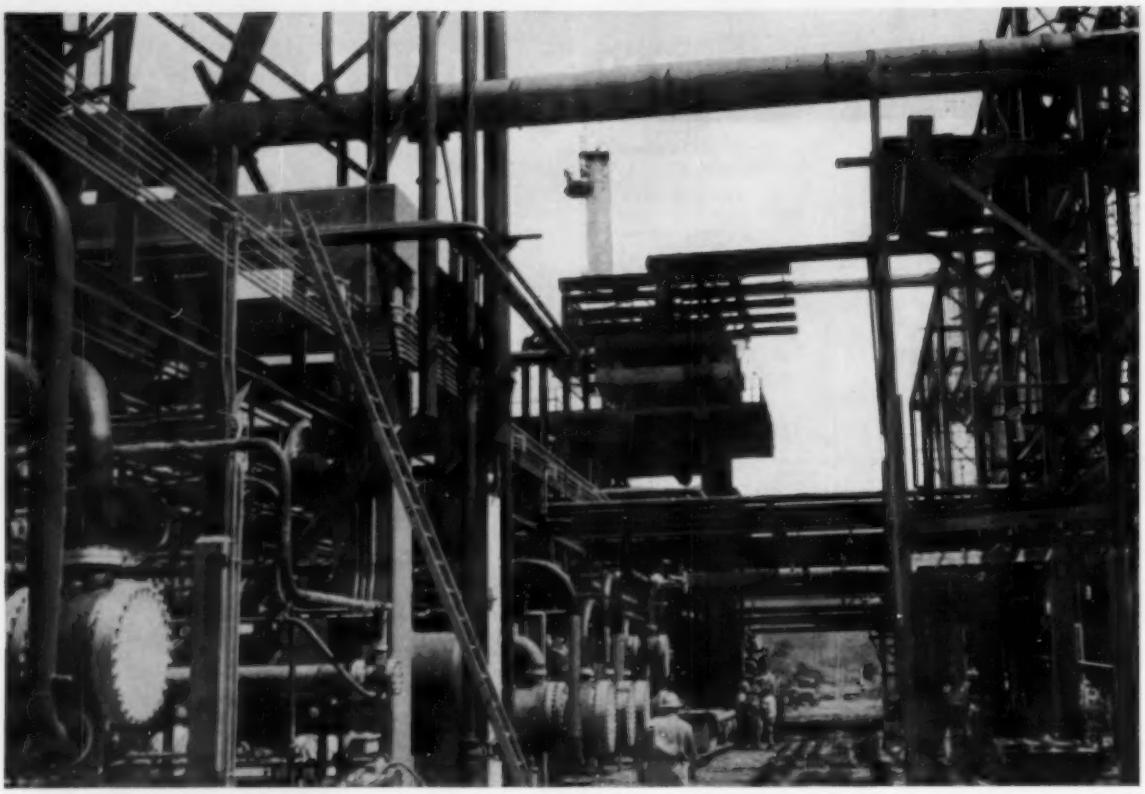
Foster R-4 Relief Valves are spring loaded, adjustable, with internal pilot operated main valve for practically instantaneous relief of excess pressure. It is one of many for all operating conditions and services.

Foster Automatic Regulating Valves for controlling pressure, temperature or level are built to suit your requirements. Each type of regulator is designed to do a specific job, and do it well. Sizes range from ¼" to 20" depending on design and on operating conditions. Catalog 80 on request. Representatives in principal cities.

FOSTER ENGINEERING COMPANY

835 LEHIGH AVENUE UNION, NEW JERSEY

AUTOMATIC VALVES ★ CONTROL VALVES ★ SAFETY VALVES ★ FLOW TUBES



Over 200,000 Sq. Ft. of Tube Surface for Commonwealth at Ponce, P. R.

In 1955 Lummus designed and built all of the heat exchangers for Commonwealth Refining Company's complete new refinery at Ponce, Puerto Rico. Well over 100,000 sq. ft. of tube surface is represented in exchangers for the atmospheric and vacuum distillation unit, Houdriflow fractionation and vapor recovery sections, Houdriformer, sulfuric acid alkylation and acid regenerating units, and catalytic polymerization unit.

Before the original refinery was placed in operation, Lummus was requested to increase the refining capacity by approximately 150%. The new addition is scheduled for completion by the end of 1956. Repeat orders on Lummus designed equipment are frequent, because Lummus heat exchangers are engineered to meet customer requirements for long and trouble-free service.

The Lummus Company has now established a standard line of heat exchange equipment to meet the requirements of TEMA Class "R" and API-ASME code requirements. Write for your free copy of Bulletin MD-164 which completely describes this equipment.

THE LUMMUS COMPANY, Heat Exchanger Division, 385 Madison Avenue, New York 17, N. Y.
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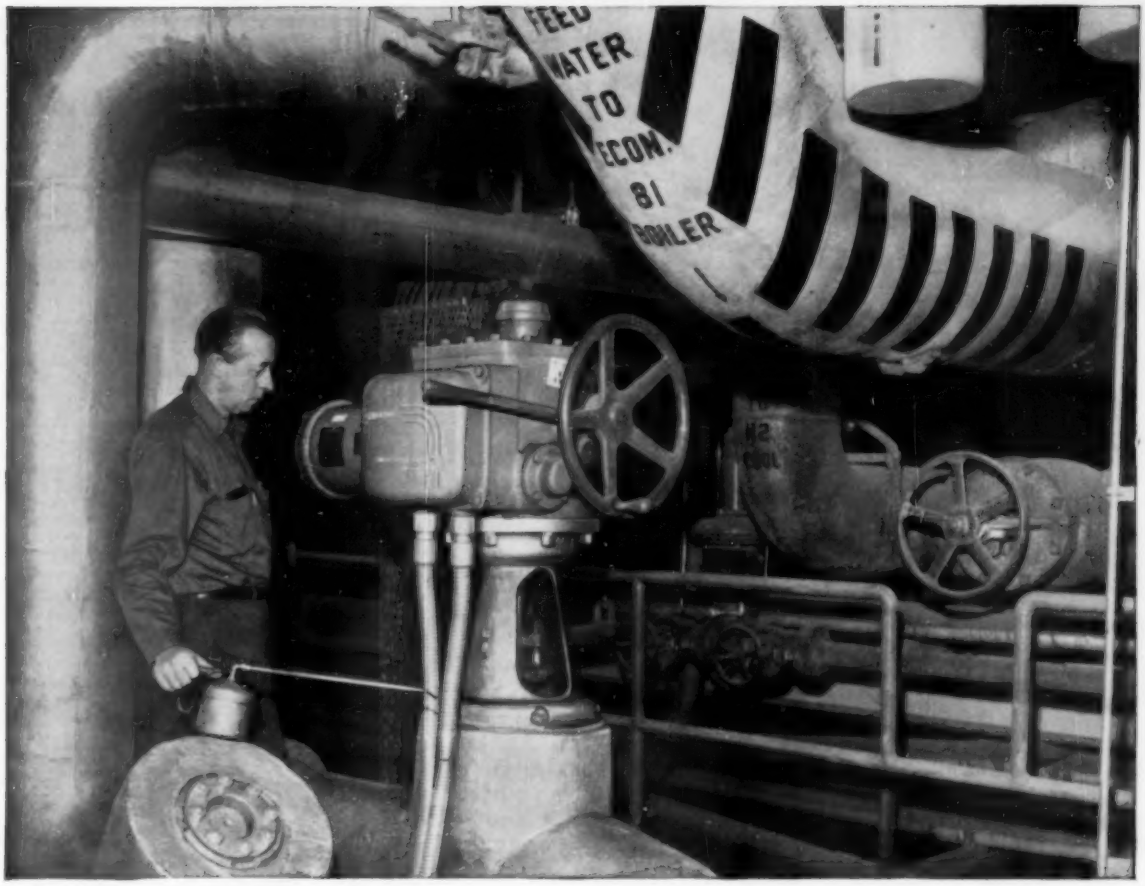
LUMMUS

THE LUMMUS COMPANY, HEAT EXCHANGER DIVISION • 385 MADISON AVENUE, NEW YORK 17, N. Y.



Lubrication—the only maintenance cost of these high-pressure Crane valves

THE CASE HISTORY—When an oil can is all you need to keep high pressure valves at peak efficiency year after year, you know your valve investment is a wise one.

That's how Philadelphia Electric Company feels about the Crane Pressure-Seal Bonnet Gate Valves at its Delaware Station—one of this utility's newest units, started up early in 1953.

The Crane valves, operating on boiler feed service at 2000 psi, 500° F., have demonstrated completely their maintenance-saving values.

The old practice of re-stressing bonnet bolts doesn't apply to these valves. Yet the body-bonnet joint remains completely tight. Never a leak; never a need for a wrench. Crane Pressure-Seal design, utilizing internal fluid pressure, maintains a positively leakproof metal-to-metal joint inside the body.

The seats and stuffing box on all valves remain equally tight. Operation is smooth, nonsticking. The Crane flexible wedge disc prevents binding under contraction.

Other value features of Crane Pressure-Seal design are compactness . . . weight saving with no loss of strength . . . and clean exterior lines that simplify insulation.

Power plants around the world report new performance records for Crane Pressure-Seal Bonnet Valves. Now's the time to consider this advanced design—in gates, globes, angles and stop-checks—for modernization or extension projects. Contact your local Crane Representative or write to address below.

CRANE VALVES & FITTINGS

PIPE • KITCHENS • PLUMBING • HEATING

Since 1855—Crane Co., General Offices: Chicago 5, Ill. Branches and Wholesalers Serving All Areas

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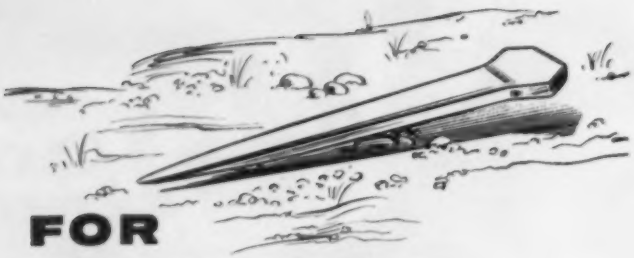

FOR WANT OF A NAIL...

Something that wasn't there once cost a king his life.

For today's boiler, lack of internal protective surfacing is hardly a life or death matter. Yet consulting engineers . . . insurance underwriters . . . power plant operators increasingly specify, recommend, and purchase Apexior Number 1 for tube and drum coating. Why?

Because the yardstick of return on investment proves Apexior's unique service *now pays off at the highest rate ever* . . . for modern boiler design and operation today permit a single Apexior application to deliver maximum protection not only for a normally anticipated five years, but for one — three — sometimes even *five years more!*

And because Apexiorizing is now a one-coat procedure, former material and labor estimates are halved. Protection that can last twice as long today costs *half as much* . . . a trifling pennies-per-square-foot premium to insure full return on a major capital investment.

Like the legendary nail, boiler protective coating may seem a factor of small significance — yet it can mean the difference between acceptable performance and the best of which the modern boiler is capable. The assurance every inspection gives that tubes and drums are functioning at new-metal peak efficiency is the measure of Apexior's service in maintaining highest steam production reliability and quality — a contribution measured ultimately in profit dollars.

Internal boiler protection is but one phase of Dampney corrosion-control activity. Dampney Coating Systems for specified end-use service protect cooling towers — intake water structures — pipeline interiors. For a recommendation to meet your requirements, write

MAINTENANCE FOR METAL

THE DAMPNEY COMPANY

HYDE PARK, BOSTON 36, MASSACHUSETTS

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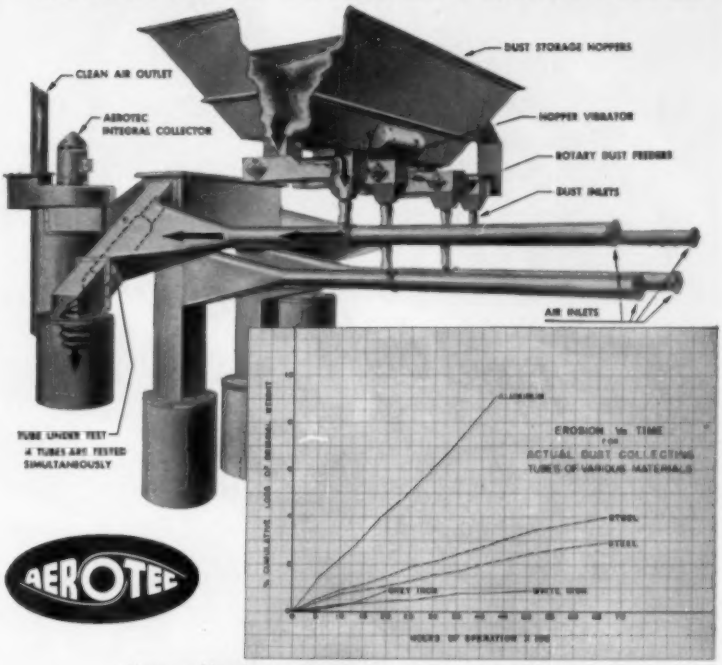
...PROVING EROSION RESISTANCE



AEROTEC

Wear machine developed in our laboratory to test resistance of various metal tubes. Above chart shows loss of weight in tubes of aluminum, steel, grey iron and white iron.

years of research by AEROTEC now assure *longer tube life* for mechanical dust collectors

Dust collector tubes of aluminum, because of the ductility of the metal, were at one time thought to be more erosion resistant than steel. However, *accelerated tests now prove conclusively that of all the basic metals tested, white cast iron tubes assure greatest resistance to abrasion.*

In setting up the test procedure, unusually severe abrasive conditions were simulated—many times more severe than ever encountered in field installations. The most troublesome dust erosion-wise was selected for the test. After 6700 hours of continuous operation, tube wear for various metals produced the curves shown on this page. Note the outstanding performance of the white iron tube. Although in many cases aluminum tubes are proving entirely satisfactory, white iron is now recommended for the majority of new installations.

In development for over three years, the new Aerotec 5" white iron tube will assure longer life and continuing high efficiency in your dust collection equipment. Why not call or write today for complete information? Address The Thermix Corporation, Project Engineers for Aerotec.

Project Engineers **THE THERMIX CORPORATION** Greenwich, Conn.
(Offices in 38 principal cities)
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Designers and Manufacturers of Automatic Controls, Valves — Regulating, Relief, and Check Type; Pressure Switches; Gauge, Altitude, Differential and Absolute Types — Float Switches: Top, bottom or side mounted — Single, Dual or Tandem.

Painting, courtesy Power Magazine

New J-M Color Code

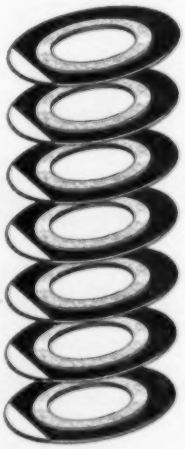
identifies metal in Spirotallic® Gaskets

Most engineers know that Spirotallic Gaskets maintain a perfect seal despite extreme fluctuation in fluid pressure and flange compression. Consequently, these gaskets are used in a wide range of service conditions which include high temperatures, elevated pressures and active corrosives. To withstand these conditions, Spirotallic Gaskets employ a variety of corrosion-resistant alloys.

Because so many of these metals look alike, only expensive tests or costly experience with the gasket could determine the gasket metal used, once its identifying tag was lost. Now the color patch on the centering guide tells the metal employed and saves time, trouble and expense. This new method of identification also makes it easier for storekeepers and mechanics who handle the gasket. In addition, it simplifies inventories.

Spirotallic Gaskets hold their seal because they are made of spirally wound interlocking plies of asbestos and spring-like metal strip. These gaskets compress easily with light bolting. For catalog PK-35A and copy of color code card write Johns-Manville, Box 60, New York 16, N. Y. In Canada, Port Credit, Ont.

Here are seven of the metals available and their color identifications



Zinc-coated steel—white

Type 304 Stainless—yellow

Type 316 Stainless—green

Type 347 Stainless—blue

Monel—orange

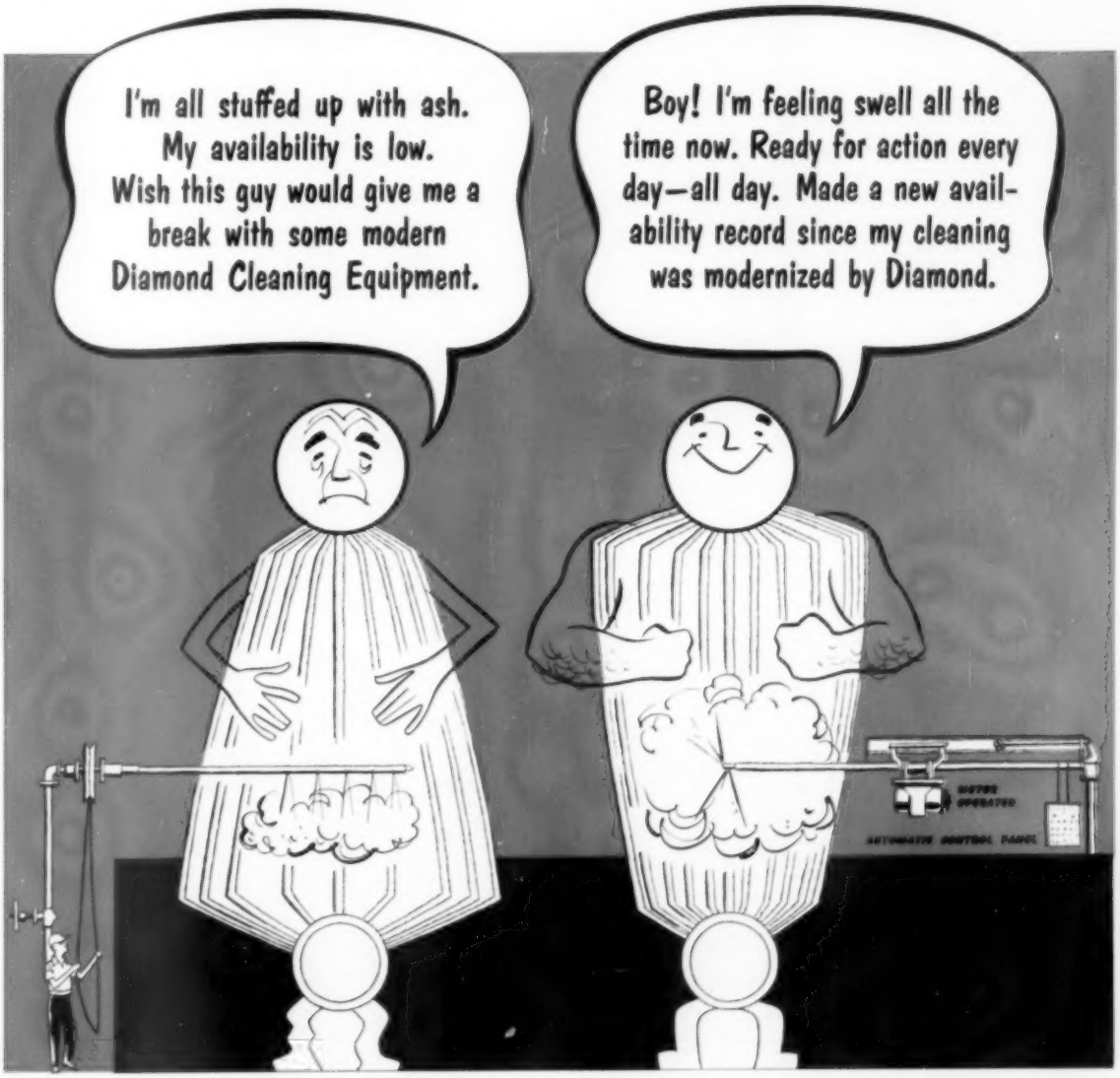
Copper—brown

Aluminum—aluminum

JM PRODUCTS

Johns-Manville SPIROTALLIC GASKETS

Modernize Boiler Cleaning to IMPROVE AVAILABILITY


I'm all stuffed up with ash. My availability is low. Wish this guy would give me a break with some modern Diamond Cleaning Equipment.
Boy! I'm feeling swell all the time now. Ready for action every day—all day. Made a new availability record since my cleaning was modernized by Diamond.

DIAMOND POWER SPECIALTY CORPORATION

LANCASTER, OHIO

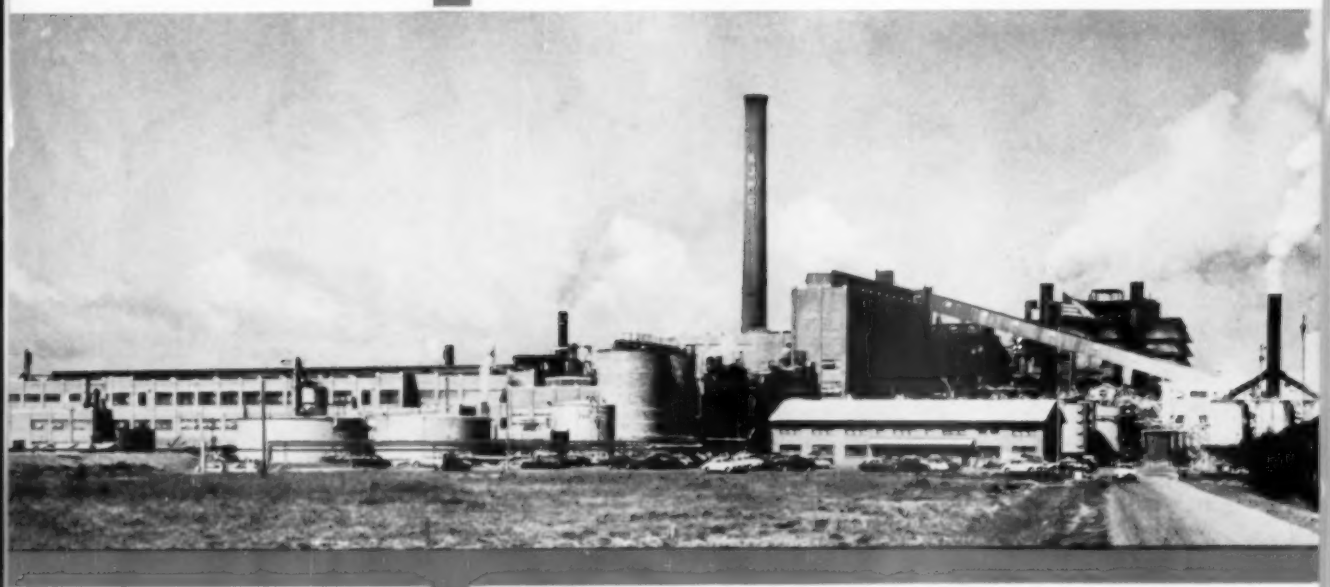
DIAMOND SPECIALTY LIMITED, WINDSOR, ONTARIO

7205

to Shaw experts the unusual is routine

Roger L. Main, president of the St. Joe Paper Company. Says Mr. Main: "We are tremendously impressed by the fact that the Shaw Company was able to complete the piping for this addition on schedule, and with no interruption to the work of the rest of the plant."

At the St. Joe Paper Company in Port St. Joe, Florida, business went on as usual all through the construction of an 800-ton expansion to the Kraft Board Liner Plant . . . one of the largest expansions of its kind ever to be completed without interrupting production at the original facilities. The job of fabricating and installing the piping for this expansion—which involved piping for process, water, air, steam, drainage, filtration, and instrumentation—went to the Shaw Company of Wilmington, Delaware. A job well done, it included the connecting of six new digesters, two recovery boilers, three power boilers, two turbines, an evaporating plant, and a paper machine—as well as piping for the 30 MGD main open waterway supply system from the Chipola River, eighteen and one-half miles away. As is its custom, Shaw set up a complete field organization—under the direct supervision of its Wilmington Construction Department—to handle material procurement, fabrication and installation work, payroll and cost accounting, and related matters. This on-the-spot service, combined with careful pre-planning and long years of diversified piping experience, enabled Shaw to complete another job economically, skillfully, and on schedule. *Your* piping job can be handled just as economically, just as skillfully, just as swiftly. Simply turn it over to Shaw . . . while you conduct your business as usual.



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